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The ammonite sequence in the Agrio Formation (Lower Cretaceous), Neuquén Basin, Argentina

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Abstract – The Agrio Formation of the Neuquén Basin, Argentina, contains an extensive sequence of ammonite faunas, most of which are monogeneric. Detailed collecting through 15 sections across the basin has facilitated a major revision of the ammonite zonation. Formerly embracing four broad zones, the Agrio Formation is now divided into nine zones, the lowest four of which are divided into a total of 11 subzones. The new zonation provides a standard against which other South American faunas can be compared. The degree of subdivision now achieved is comparable to that for the 'standard' sequences of the West Mediterranean region. Although it is not possible to correlate the two regions in detail, the occurrence of some widely distributed genera (*Olcostephanus, Karakaschiceras, Oosterella, Spitidiscus* and *Crioceratites*) at well-defined levels in the Neuquén Basin provides some crucial links. Thus the approximate positions of the Lower/Upper Valanginian, Valanginian/Hauterivian and Lower/Upper Hauterivian boundaries can be determined.

1. Introduction

The Agrio Formation of the Neuquén Basin (west-central Argentina) contains one of the most important mid-Valanginian to early Barremian (early Cretaceous) ammonite faunas in the Southern Hemisphere. The faunas consist of both endemic and more widely distributed genera. Although some of the taxa have been well documented, important elements of the fauna remain poorly known or await description, and new discoveries are still being made (e.g. Leanza & Wiedmann, 1992; Aguirre Urreta & Rawson, 1993, 1996).

The stratigraphy of the faunas is also poorly documented. The purpose of this paper is to demonstrate the sequence of faunas in the Agrio Formation, based primarily on extensive new collections that we have made in 15 sections across the basin. Comparisons are made with the European faunas to improve the chronostratigraphic dating of the Argentine sequence.

2. Regional setting

The Neuquén Basin (Figs 1, 2) is a back-arc basin formed on a convergent continental margin (Legarreta & Uliana, 1991) and is one of five discrete early Cretaceous basins in the southern Andes (Aguirre Urreta, 1993). It formed an extensive, northwest–southeast orientated marine embayment largely land-locked but opening northwestwards to the Pacific. During the Mendocian marine cycle (Tithonian to early Barremian) up to 3000 metres of sediments accumulated, consisting of shales, sandstones and carbonates, interfingering with volcaniclastics to the west. The general succession of the Mendoza Group is shown in Figure 3.

3. The Agrio Formation

The Agrio Formation occurs over much of the Neuquén Basin, forming extensive outcrops in the western half. It extends from the vicinity of La Mala Dormida (Locality 1

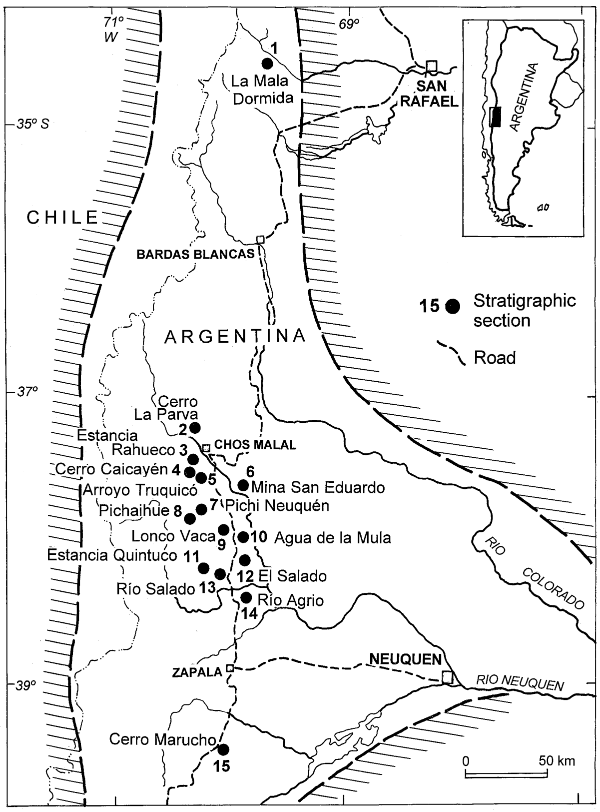

Figure 1. The Neuquén Basin in west-central Argentina, showing the location of the 15 sections studied.

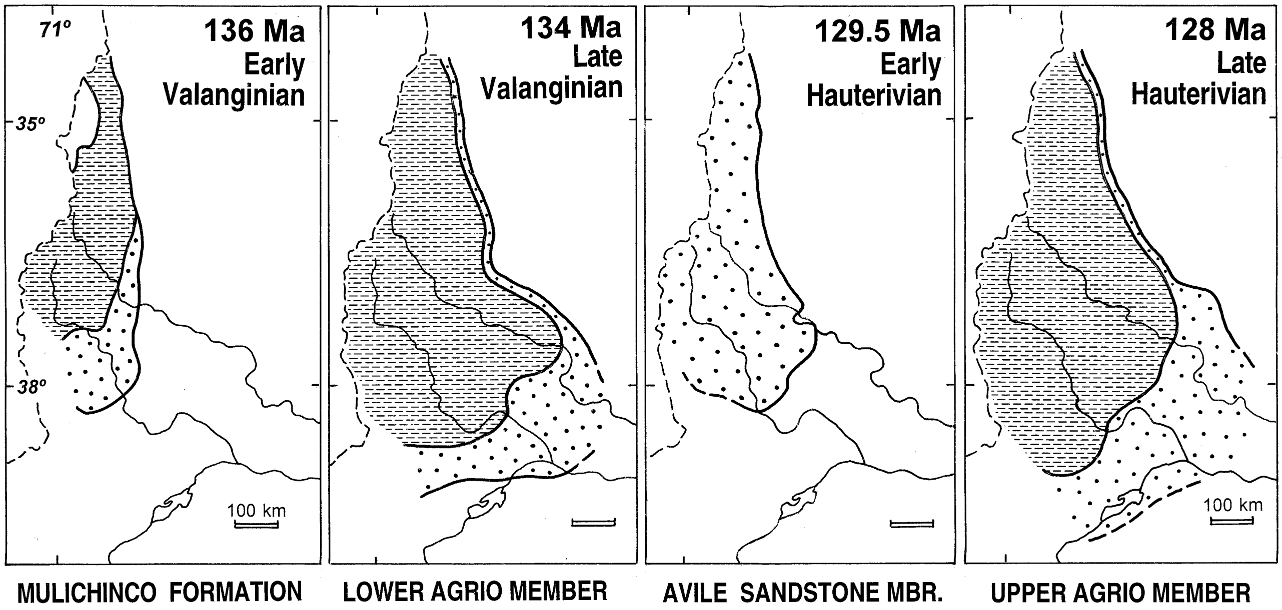

Figure 2. Valanginian–Hauterivian palaeogeography of the Neuquén Basin (modified from Legarreta & Uliana, 1991).

in Fig. 1) in southern Mendoza southwards to Catan Lil, a few kilometres to the south of Cerro Marucho (Locality 15 in Fig. 1) in southern Neuquén. To the west, the boundary of present outcrops coincides with the foothills of the Andes (70°30′ W). Eastwards the formation passes beneath younger Cretaceous rocks, eventually passing laterally into continental red beds of the Centenario Formation. To the south there is a lateral passage into another sequence of continental red beds, the La Amarga Formation. The Agrio Formation grades upwards to the evaporites and limestones of the Huitrín Formation.

Weaver (1931, p. 53) named the Agrio Formation for a thick sequence (max. *c.* 1600 m) of marine shales overlying the Mulichinco Formation. The latter was described as "massive sandstones and conglomerates with interbedded sandy shales which are of continental origin". In practice, the boundary between the two formations is difficult to define in some of the more basinal localities. There is often a gradation from a non-marine, predominantly sandstone unit with thin silty shale interbeds to brownish-coloured, marine silty shales with thin sandstone interbeds, before black silty shales eventually appear. But thin marine beds may also occur lower in the sequence, within typical Mulichinco sandstones. If the base of the first thick marine shale unit (or of the first black shale) is taken to mark the base of the Agrio Formation, then its base is diachronous, as marine sedimentation recommenced in the centre of the basin while Mulichinco facies sands continued to accumulate towards the margins. Because of this, some authors have defined the boundary chronostratigraphically and thus included the lowest 'Agrio' facies of the basin centre in the Mulichinco Formation (e.g. Leanza & Wiedmann, 1980, p. 944). We follow a strictly lithostratigraphic approach (Aguirre Urreta & Rawson, 1995*a*).

Weaver (1931) divided the Agrio Formation into lower and upper divisions separated by a thin but laterally persistent sandstone, the Avilé Sandstone (Figs 2, 3). The three divisions are generally regarded as members. Both the lower and upper Agrio members are marine. The lower member (max. *c.* 600 m) is composed mainly of thick clay shales interbedded with thin sandy limestone beds (packstones and wackestones). Towards the top of the lower member, shales become dominant. The upper member (max. *c.* 1000 m) is composed largely of thick clay shales in the lower part and gray calcareous clay shales interbedded with sandy limestones and sandstones in the upper part (Weaver, 1931; Uliana, Dellape & Pando, 1977). On the other hand, the intervening Avilé Sandstone Member consists of some 25–30 metres of grayish-brown to cream-coloured, coarse sandstones, often cross-bedded. It is non-marine and marks a significant fall in sea-level across the basin. The sandstone provides an excellent marker horizon, generally forming a distinct topographic feature. In this analysis we have studied fifteen sections of the Agrio Formation (Figs 1, 4).

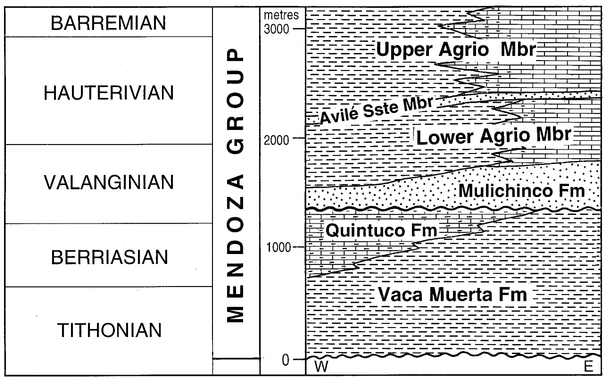

Figure 3. Schematic stratigraphic section of the Mendoza Group.

STRATIGRAPHIC SECTION / AMMONITE ZONES / SUBZONES	1 LA MALA DORMIDA	2 CERRO LA PARVA	3 ESTANCIA RAHUECO	4 CERRO CAICAYÉN	5 ARROYO TRUQUICÓ	6 MINA SAN EDUARDO	7 PICHI NEUQUÉN	8 PICHAIHUE	9 LONCO VACA	10 AGUA DE LA MULA	11 EST QUINTUCO	12 EL SALADO	13 RÍO SALADO	14 RÍO AGRIO	15 CERRO MARUCHO
Paraspiticeras groeberi						●	●			●		●	●	●	
Crioceratites diamantensis	●	●					●	●	●	●		●	●	●	
Crioceratites schlagintweiti						●	●			●		●			
Spitidiscus riccardii		●								●		●		●	
AVILE SANDSTONE															
Weavericeras vacaensis		●				●	●	●	●	●		●	●	●	●
Hoplitocrioceras gentilii		●				●		●	●	●		●		●	●
Hoplitocrioceras sp. nov.		●		●		●				●					
Olcostephanus leanzai	●			●		●			●	●				●	●
Holcoptychites compressum				●		●			●	●			●	●	
Holcoptychites neuquensis	●					●	●	●	●	●		●	●	●	
Neocomites sp.						●		●	●	●		●	●		
"Acanthodiscus" sp.					●	●		●	●	●	●		●		
Pseudofavrella angulatiformis	●	●		●	●	●	●	●	●	●	●		●		
Lemurostephanus sp.				●		●	●	●	●						
Karakaschiceras attenuatus		●	●	●	●										
Olcostephanus atherstoni		●	●	●	●			●							

Figure 4. Valanginian–Barremian ammonite horizons in 15 key sections (shown in Fig. 1) of the Neuquén basin.

Lithic logs to varying degrees of detail have been compiled for almost all of them, to provide a clear framework for establishing the ammonite sequence.

4. The ammonite sequence

The Agrio Formation contains an abundant ammonite fauna of Valanginian to Barremian age. Until recently the ammonite succession was divided into only four ammonite zones (Fig. 5), of rather broad vertical extent (Gerth, 1925; Leanza, 1945; reviewed by Riccardi, 1988). Then, for the Upper Agrio Member, Aguirre Urreta & Rawson (1993) divided the former *andinus* Zone into two and recognized an overlying zone of *Paraspiticeras groeberi*. Aguirre Urreta, Gutiérrez Pleimling & Leanza (1993) subsequently identified the true position of the *Spitidiscus* fauna recorded by Leanza & Wiedmann (1992) and proposed the *Spitidiscus riccardii* Zone for beds immediately above the Avilé Sandstone.

The Lower Agrio Member embraces a large number of distinctive ammonite faunas. They allow a much more refined subdivision to be made than any previously published. The *atherstoni* (formerly *curacoensis*) and overlying *angulatiformis* zones are divided here into three subzones each. The former *neuquensis* Zone is divided into three zones, *Holcoptychites neuquensis* being retained as index for the lowest of the three. Two of the three zones are each divided into two subzones. The proposed zonation is summarized in Figure 5.

Because of the vagaries of occurrence, preservation and exposure in such a vertically and laterally variable sequence as the Agrio Formation, we have not been able to prove all the faunal horizons in any one sequence. In three sections (Estancia Rahueco, Arroya Truquicó and Estancia Quintuco) we have concentrated on a very limited part of the section. The remainder of the fifteen sections that we have studied contain several distinct faunas while all the zones and subzones that we recognize are known from several sections (Fig. 4).

At most horizons taxonomic diversity is small, individual assemblages generally being monogeneric or even monospecific. The sequence consists of a mixture of globally or widely distributed taxa (*Olcostephanus, Karakaschiceras, Oosterella, Spitidiscus, Crioceratites*) and more geographically restricted genera. The latter group includes forms found also in the Indo-Malagasian Province and Andean genera. Some of the genera are in need of taxonomic revision; the main outstanding

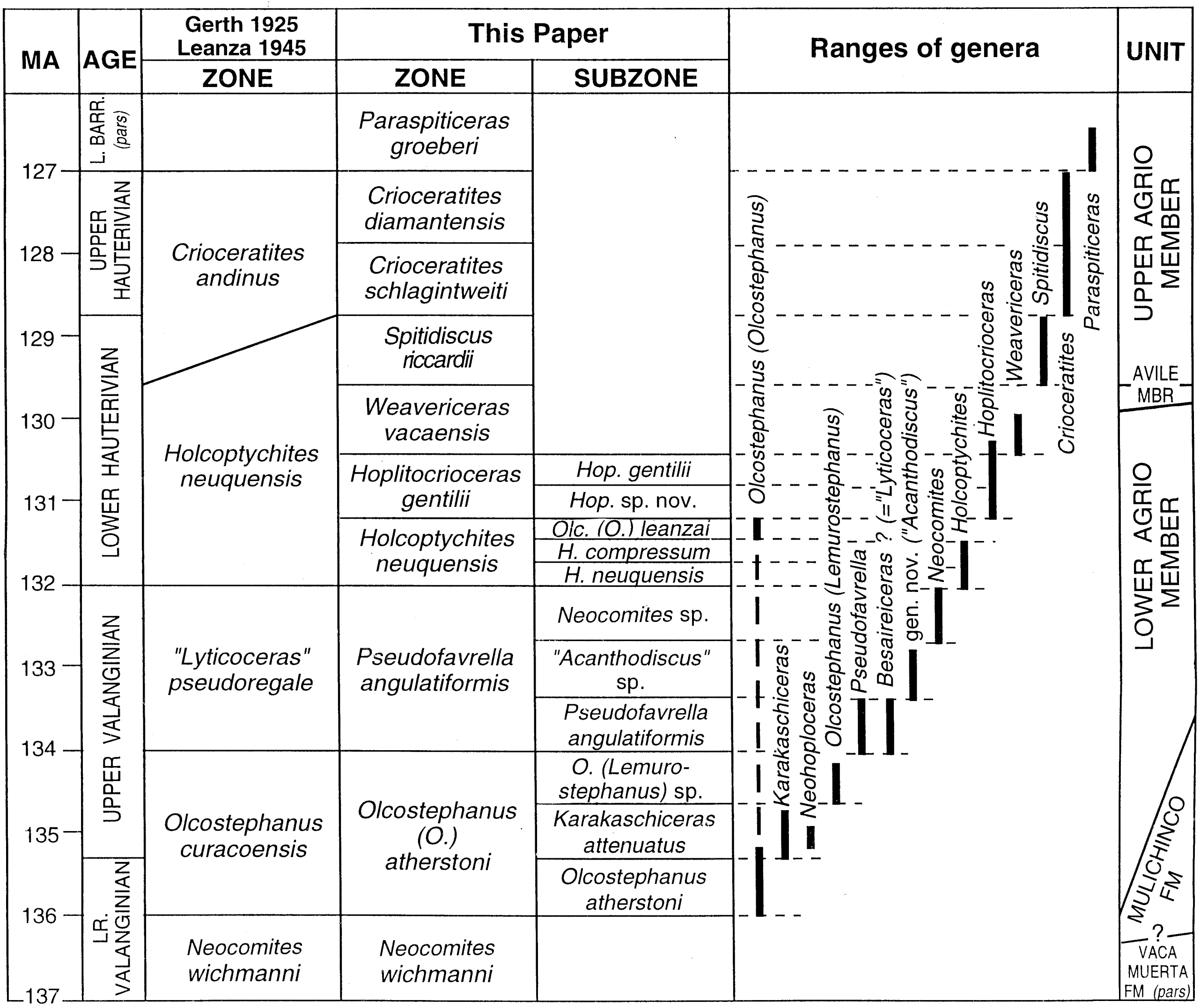

Figure 5. Present and former zonations of the Valanginian–Barremian of the Neuquén Basin. The ranges of all genera are indicated. The numerical time-scale is based on Gradstein *et al.* (1996).

taxonomic problems are indicated below (Sections 4.a–h). In Figures 6 and 7 we illustrate some of the key ammonites, but many have been illustrated in four readily accessible papers (Riccardi, Westermann & Levy, 1971; Leanza & Wiedmann, 1980; Riccardi, 1988; Aguirre Urreta, 1993), to which we cross-refer.

4.a. The *Olcostephanus atherstoni* Zone

This is a new name for the former zone of *Olcostephanus curacoensis* (named by Leanza, 1945). It is renamed because we regard the original index species as a junior subjective synonym of *O. atherstoni* (Sharpe). This was provisionally suggested by Riccardi, Westermann & Levy (1971, pp. 91, 103), who illustrated the range of variation shown by *O. atherstoni.*

The *atherstoni* Zone occurs in a thick sequence of sediments that include three distinctive faunas, regarded here as subzones (Fig. 5). The subzones can be distinguished in the central part of the basin, but some of the distinctive faunas apparently disappear towards the basin margins.

The base of the zone, and of the *atherstoni* Subzone, is defined by the first appearance of *Olcostephanus atherstoni*, which is often within the upper part of the Mulichinco Formation. At Arroyo Truquicó, Estancia Rahueco and Cerro La Parva, large specimens occur in abundance in a coquina near the base of the Agrio Formation. At Arroyo Truquicó and Cerro La Parva, the lowest few metres of the beds overlying the coquina contain abundant smaller specimens (typically 40–120 mm diameter) of *Olcostephanus* alone, often body chambers (Fig. 6h, i).

The base of the overlying *Karakaschiceras attenuatus* Subzone is marked by the sudden appearance of abundant neocomitids, mainly *Karakaschiceras*. Numerous examples were figured by Riccardi, Westermann & Levy (1971) and Aguirre Urreta (1997). *Olcostephanus* still occurs in the lowest beds but disappears upward to leave *Karakaschiceras* alone, represented by the discoidal species *K. attenuatus*. *Neohoploceras arnoldi* is restricted to the lower part of the *Karakaschiceras attenuatus* Subzone, overlapping with *Olcostephanus*.

The *O.* (*Lemurostephanus*) sp. Subzone appears higher in the sequence. It was first named by Aguirre Urreta & Rawson (1995*a*), who separated it from the upper part of the *curacoensis* (= *atherstoni*) Zone as a distinct zone. We now prefer to reduce it to the rank of a subzone in order to retain the original scope of the *atherstoni* Zone.

The base of the subzone is defined by the first appearance of evolute olcostephanids, which occur above the last *Karakaschiceras* and just beneath the *Pseudofavrella angulatiformis* fauna. This distinctive *Lemurostephanus* fauna (Fig. 6a, b) marks the return of olcostephanids to the basin. The fauna was first described by Leanza (1958), who recognized four species and assigned them to the boreal genus *Simbirskites*. Rawson (1971, p. 42) suggested that the fauna was closer to the olcostephanid genus *Rogersites* (now synonymized with *Olcostephanus*) while Leanza & Wiedmann (1980) subsequently reassigned it to the *Olcostephanus* subgenus *Lemurostephanus* Thieuloy, a classification followed here. The fauna was originally described from the Lower Agrio Member near Ñorquín,

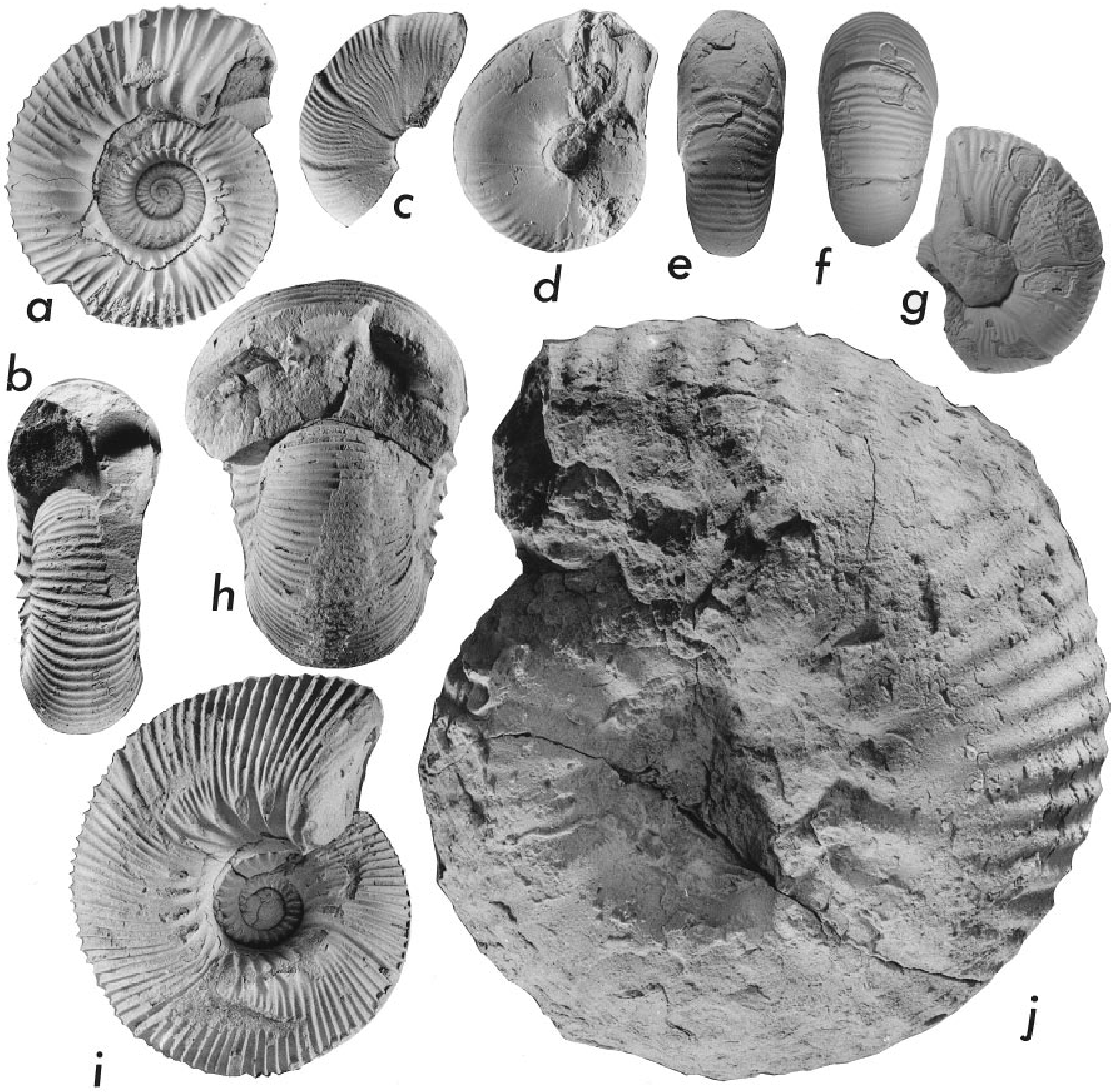

Figure 6. Olcostephanid and holcodiscid ammonites from the Neuquén Basin. All specimens are deposited in the Palaeontological Collections of the University of Buenos Aires (CPBA) except for the original of Figs a, b, d and e. All photographs × 1. (a, b) *Olcostephanus (Lemurostephanus) permolestus* (Leanza), *O. (L.)* sp. Subzone, Ñorquín (Cordoba University, Mingramm collection P2 3344); (c) *Spitidiscus riccardii* Leanza & Wiedmann, *riccardii* Zone, Agua de la Mula (CPBA 17026-7); (d, e) *Spitidiscus riccardii* Leanza & Wiedmann, *riccardii* Zone, Agrio del Medio (holotype; Museo Olsacher, Zapala, P 1749); (f, g) *Spitidiscus* sp. nov.; *riccardii* Zone, El Salado (CPBA 18049); (h, i) *Olcostephanus (O.) atherstoni* (Sharpe), *atherstoni* Zone, Cerro la Parva (CPBA 17008-52); (j) *Olcostephanus (O.) leanzai* (Giovine), *leanzai* Subzone, Cerro Marucho (CPBA 13973).

30 km southwest of Locality 4 (Cerro Caicayén). We have collected specimens from a similar horizon at several localities. Until we have revised the fauna it is not appropriate to name the subzone after a particular species.

4.b. The *Pseudofavrella angulatiformis* Zone

The zonal name was proposed by Aguirre Urreta & Rawson (1995*a*) as a replacement for the former '*Lyticoceras*' *pseudoregale* zone, as *Pseudofavrella* is such a characteristic and distinctive component of the lowest beds. In addition, '*L.*' *pseudoregale* is a poorly known species and the name has been applied to neocomitids from several different horizons, some much higher in the sequence.

Three subzones are recognized. The *P. angulatiformis* Subzone at the base contains a *Pseudofavrella*–*Besairieceras* assemblage, beautifully preserved at Pichaihue but more widely preserved as abundant flattened impressions in shale. The sudden appearance of these genera represents a major reinvasion of the basin by neocomitid ammonites. While *Pseudofavrella* (Fig. 7h, i) is endemic to the Andean region, the accompanying '*Lyticoceras/Acanthodiscus*' fauna has been compared with European examples of those genera and therefore dated as early Hauterivian (e.g. *Acanthodiscus* aff. *radiatus* in Gerth, 1925; *Acanthodiscus vaceki* in Leanza & Wiedmann, 1980). However, Aguirre Urreta & Rawson (1995a) suggested that they are congeneric with the Indo-Madagascan genus *Besairieceras*, of late Valanginian age. They noted also that the '*Acanthodiscus vaceki* (Neumayr & Uhlig)' *sensu* Leanza & Wiedmann (1980) is simply a more advanced growth stage of '*Lyticoceras*' *australe* Leanza & Wiedmann 1980, unrelated to the true *A. vaceki* of Neuymar & Uhlig (1881) or other early Hauterivian *Acanthodiscus*.

The '*Acanthodiscus*' sp. Subzone is characterized by a single species, recorded previously as *Acanthodiscus* ex aff. *A. hookeri* (e.g. Leanza & Wiedmann, 1980, pl. 7, fig. 1) or *Acanthodiscus* aff. *radiatus* (e.g. Gerth, 1925, pl. 3, fig. 1). This is not a true *Acanthodiscus* and will be described as a new genus and species (Aguirre Urreta & Rawson, unpub. data). Two specimens were figured by Aguirre Urreta & Rawson (1995*a*, pl. 2d, e) and a larger fragment is illustrated here (Fig. 7a, b). The taxon is very distinctive and is known from several localities, clearly at a higher level in the Lower Agrio Member than the *Pseudofavrella/Besairieceras* fauna. It may be a spinose, trituberculate derivative of *Pseudofavrella*.

The '*Neocomites*' sp. Subzone again occurs at several localities, though the characteristic ammonites are often crushed or fragmentary and the specimens shown in Figure 7d–f are the first ever figured. The fauna differs from the underlying one in consisting of involute, compressed ammonites here assigned to *Neocomites*. Some examples are closely comparable in lateral view with European forms of the *Neocomites (Teschenites) pachydicranus* group.

4.c. The *Holcoptychites neuquensis* Zone

As originally defined (Gerth, 1925, p. 182), the zone embraces several clearly distinct faunal horizons, occurring up to the base of the Avilé Member. Its use is restricted here to embrace only those beds characterized by *Holcoptychites*, plus a thin horizon immediately above which contains *Olcostephanus.*

The base of the zone is marked by the first appearance of *Holcoptychites*, a genus that is endemic to the basin but could be an early holcodiscid related to *Jeanthieuloyites*. *Holcoptychites* shows a superficial similarity to *Jeanthieuloyites quinquestriatus* from Madagascar (Cooper, 1981, p. 261, fig. 110) and France (Autran, 1993, pl. 1, fig. 4). Thieuloy, Fuhr & Bulot (1990, p. 80) recorded the same species from the top of the *verrucosum* Zone and the *trinodosum* Zone in France. They regard *Jeanthieuloyites* as the oldest holcodiscid.

Holcoptychites shows considerable variation in strength of ribbing and development of constrictions and slight flares. Thus two *Holcoptychites* subzones are recognized, reflecting an upward gradation from the more inflated, quite strongly ribbed forms of the *H. neuquensis* group (e.g. Leanza & Wiedmann, 1980, pls 2, 8) to the more compressed, ribbed to nearly smooth forms separated by Leanza & Wiedmann (1980, pl. 3) as *H. compressus*. A revision of the genus and its occurrences is in progress.

A single *Hoplitocrioceras* has been found in the upper beds (*compressus* Subzone) at the Agua de La Mula section.

Above comes the *Olcostephanus leanzai* Subzone. This is marked by a brief reappearance of *Olcostephanus* in the Neuquén Basin. It occurs alone, and although not common, has been found at several localities. Unfortunately most individuals are abraded (Fig. 6j).

4.d. The *Hoplitocrioceras gentilii* Zone

This zone is proposed for the middle part of the *Holcoptychites neuquensis* Zone of previous authors. The horizon of the very evolute necomitid *Hoplitocrioceras* has not been recorded previously, and it has even been assigned to the Upper Agrio Member (Riccardi, 1988). The base of the zone, and of the *H.* sp. nov. Subzone, is placed at the level where *Hoplitocrioceras* abruptly replaces *Olcostephanus* in the sequence. Early forms *(H.* sp. nov.) are thick-whorled and very evolute, almost *Acanthodiscus*-like. They are replaced upwards by a more compressed form, *H. gentilii* (Fig. 7g). *Hoplitocrioceras* is only recorded from the Neuquén Basin, but may occur also in Colombia (*Acanthodiscus* cf. *radiatus* in Haas, 1960, p. 42, figs 102–106) and Mexico (*Acanthodiscus magnificus* in Imlay, 1938, pl. 9, figs 7, 8).

4.e. The *Weavericeras vacaensis* Zone

Hoplitocrioceras is suddenly replaced by the desmoceratid genus *Weavericeras*, which extends through the

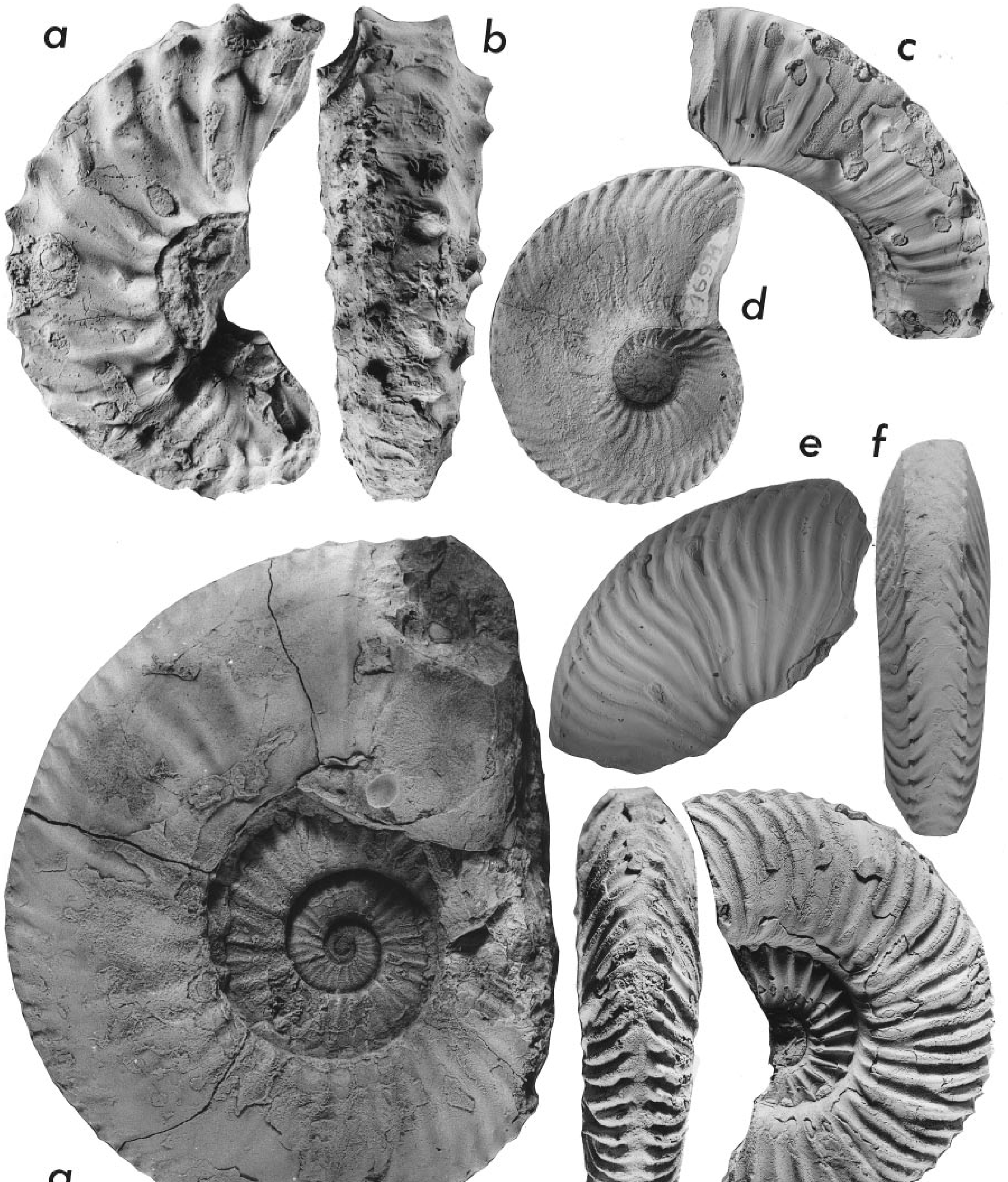

Figure 7. Neocomitid and crioceratitid ammonites from the Neuquén Basin. All specimens are deposited in the Palaeontological Collections of the University of Buenos Aires (CPBA). All photographs x 1. (a, b) "*Acanthodiscus*" sp. nov., "*Acanthodiscus*" sp. Subzone, Pilmatue (CPBA 16965-1); (c) *Crioceratites apricus* (Giovine), *schlagintweiti* Zone, El Salado (CPBA 18050); (d) *Neocomites* sp. nov., *Neocomites* sp. Subzone, unit V6, Lonco Vaca (CPBA 16971) (slightly abraded specimen); (e, f) *Neocomites* sp. nov., *Neocomites* sp. Subzone, Lonco Vaca (CPBA 18051); (g) *Hoplitocrioceras gentilii* Giovine, *gentilii* Subzone, Agua de la Mula, bed M20 (CPBA 18118); (h, i) *Pseudofavrella angulatiformis* (Behrendson), *angulatiformis* Subzone, Pichaihue (CPBA 18052).

remainder of the Lower Agrio Member, up to the contact with the Avilé Member. No other ammonites have been discovered in this zone.

Weavericeras shows some variation in degree of inflation but may represent a single variable species. It could be a derivative of *Holcoptychites*.

4.f. The *Spitidiscus riccardii* Zone

This zone was proposed by Aguirre Urreta, Gutiérrez Pleimling & Leanza (1993) for a sequence of black shales immediately above the Avilé Member, in which *Spitidiscus* appears. Previously these beds were included tentatively in either the basal part of the former *Crioceratites andinus* Zone (e.g. Leanza, 1981, p. 568) or in the highest part of the former *Holcoptychites neuquensis* Zone (e.g. Weaver, 1931, p. 57; Leanza & Wiedmann, 1980, fig. 2). Two forms of *Spitidiscus* occur. As they have not been found in the same section we remain uncertain of their order of occurrence. One, newly recorded here (Fig. 6f, g), is a moderately inflated form that appears close to a small example of *S. rotula inflatus* figured from southeastern France by Thieuloy (1972, pl. 2, figs 4–5). The other form, *Spitidiscus riccardii*, has bundled ribs, feeble constrictions and slightly raised ribs adjacent to the constrictions (plus a moderately compressed shell in some specimens) (Figs 6c–e and Aguirre Urreta, 1995, pl. 1). These features are characteristic also of *S. fasciger* Thieuloy (1972, p. 35, pl. 3, figs 4–9). *S. fasciger* appears to be more involute but the Argentinian species is mainly known only from body chambers which could be more evolute than preceding whorls. *S. fasciger* first appears in the highest part of the *loryi* Zone in southeast France, but reaches its peak in the lowest part of the *nodosoplicatum* Zone, where *S. rotula inflatus* also occurs. This is the level of the main 'mid Hauterivian' sea level rise, when there was much faunal interchange with the boreal sequence in northwest Europe. So it is suggested that the sudden appearance of *Spitidiscus* in Argentina may reflect the same event, and that it is a true immigrant rather than a later derivative of *Weavericeras*.

4.g. The *Crioceratites schlagintweiti* Zone

This zone was proposed by Aguirre Urreta & Rawson (1993) for the lower part of the former *Crioceratites andinum* Zone. It includes those beds immediately above the *riccardii* Zone in which the earliest crioceratitids appear, *Crioceratites schlagintweiti* and *C. apricus* (holotypes refigured by Riccardi, 1988, pl. 8, figs 1, 2, pl. 7, figs 3, 4; Aguirre Urreta, 1993, pl. 4, fig. 3, pl. 3, fig. 7).

The fauna is restricted geographically to the central part of the Neuquén Basin. The typical morphotype of *C. schlagintweiti* is limited to the specimens described and figured by Giovine (1950) from Estancia Gallardo, in Covunco Centro, near Zapala. However, similar forms are also common in other localities, such as Pichi Neuquén and Cerro Bayo. *C. apricus* is only known by the type specimen from Cerro Curaco (Giovine, 1952) and a fragment figured here from El Salado (Fig. 7c). Both species closely resemble the European group of *C. nolani* and *C. duvali* (regularly open coiled forms, with a variable number of fine intermediate ribs, intercalated with stronger ribs with or without tubercles) characteristic of the European 'mid' Hauterivian.

4.h. The *Crioceratites diamantensis* Zone

The zone was proposed by Aguirre Urreta & Rawson (1993) for the upper part of the former *Crioceratites andinus* Zone. It can be recognized over much of the basin, from southern Mendoza to central-south Neuquén. The nominal species is the more common, and its first appearance defines the base of the zone. It is usually associated with *Crioceratites andinus*. The holotypes of both species were refigured by Aguirre Urreta (1993, pl. 3, fig. 8, pl. 4, fig. 1). As these Neuquén Basin crioceratitids are under revision, we prefer to avoid using other specific names (such as *C. bederi* and *C. perditum*) which are probably junior synonyms of either *C. diamantensis* or *C. andinus*.

The *Crioceratites* of the *diamantensis* Zone are more involute and compressed than the underlying crioceratitids, from which they are probably derived. The tendency to recoil demonstrated by this fauna parallels that seen in the change from *Crioceratites* to *Pseudothurmannia* in western Tethys. Hence the fauna is assigned here to the latest Hauterivian.

4.i. The *Paraspiticeras groeberi* Zone

This zone was created by Aguirre Urreta & Rawson (1993) for a discrete fauna occurring above the *Crioceratites*-bearing beds. It is is characterized by a single species originally collected from eight localities across the basin. It has since been found in at least four more sections. The base of the zone is marked by the first appearance of *Paraspiticeras*. The stratigraphic position is equivalent to the beds with *Silesites* aff. *vulpes* and *Holcodiscus suesini* from the Sierra de la Cara-Cura (southern Mendoza) assigned to the Barremian by Groeber (1933). The highest beds of the Agrio Formation have yet to yield ammonites and are thus only provisionally placed in the upper part of this zone.

5. Comparison with the standard European sequences

Brief invasions of genera found also in the western Mediterranean area (western Tethys) provide important ties with the standard west European sections (Fig. 8). Thus the sudden appearance of *Olcostephanus* of the *O. atherstoni* group, followed by an incursion of *Karakaschiceras–Neohoploceras* spp., provides a clear correlation with the European 'mid-' Valanginian. The *O. atherstoni* figured by Riccardi, Westermann & Levy

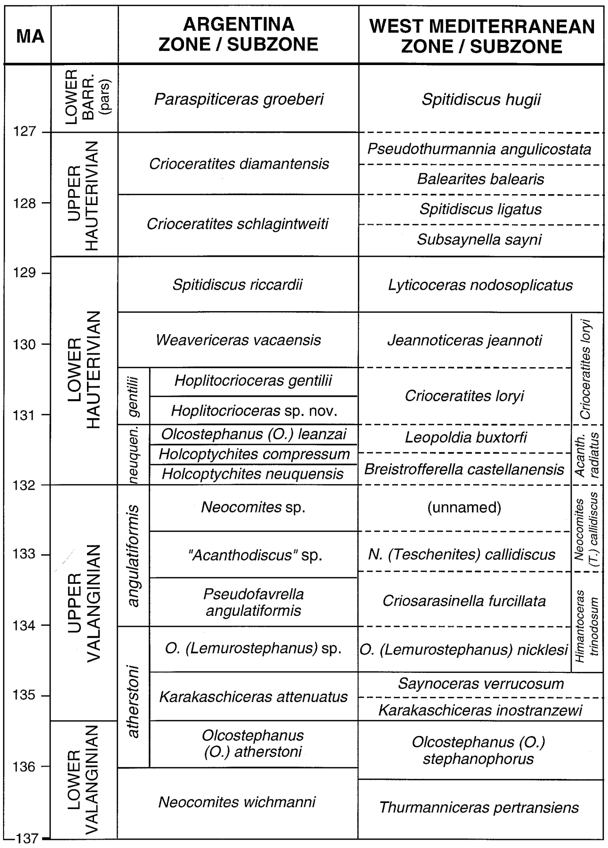

Figure 8. Tentative correlation of the Argentine zonation with the standard West Mediterranean zonation. On the right hand column, solid horizontal lines indicate a confident correlation with the Neuquén sequence; dashed lines indicate provisional or speculative correlations.

(1971) may be close to *O. guebhardi* (Luc Bulot, pers. comm.), which in southeastern France reaches its acme in the upper part of the *stephanophorus* Zone. *Karakaschiceras* and *Neohoploceras* both appear at the base of the overlying *inostranzewi* Zone and range through the whole of the *verrucosum* Zone (Bulot & Thieuloy, 1994, tables 2–3).

The Argentine *Lemurostephanus* fauna may also have its European counterpart. Comparable forms have been recorded recently from the southeast of France. There, a similar fauna occurs in the *nicklesi* horizon (lower *trinodosum* Zone). From the more condensed horizons of the Provençal facies, Autran (1993) recorded two ammonites that he compared with Argentinian species. One (Autran, 1993, p. 122, pl. 4, fig. 2), from the highly condensed Upper Valanginian sequence at Collet des Boules, near Peyrolles, was compared with the (larger) *Olcostephanus (L.) permolestus* figured by Leanza & Wiedmann (1980, pl. 2, fig. 1). The other (Autran, 1993, p. 123, pl. 4, fig. 3), from a reworked Upper Valanginian horizon at Clausson, was identified as *O. (O.) cf. quadripartitus*.

Another very important correlation is indicated higher in the Neuquén sequence by the appearance of *Spitidiscus* comparable with European mid-Hauterivian forms from the *nodosoplicatum* Zone, closely followed by *Crioceratites* similar to species from the *sayni* to lower *ligatus* Zones.

Between the *Lemurostephanus* and *Spitidiscus* levels are several important faunal horizons whose age is less clear. In the absence of ammonites characteristic of the basal Hauterivian of the west Mediterranean area the position of the Valanginian/Hauterivian boundary within the Neuquén sequence remains uncertain. The *Pseudofavrella angulatiformis* Zone (formerly the *'Lyticoceras' pseudoregale* Zone) was traditionally placed in the Hauterivian, but Aguirre Urreta & Rawson (1995*a,b*) have now assigned it to the Valanginian as the characteristic neocomitids of the lowest subzone appear close to *Besairieceras* of the Indo-Malagasian Province. Furthermore, the occurrence higher in the *angulatiformis* Zone of forms apparently close to *Neocomites (Teschenites) pachydicranus* may indicate a correlation of the *Neocomites* sp. Subzone with the upper part of the *callidiscus* Zone.

At present we place the base of the Hauterivian at the base of the *Holcopychites neuquensis* Zone (Aguirre Urreta & Rawson, 1995*b*). This is supported by the recent discovery of two poorly preserved fragments of *Oosterella* (Aguirre Urreta & Rawson, 1996). One is from the upper part of the *angulatiformis* Zone (*Neocomites* sp. Subzone) and the other from the basal part of the overlying *Holcoptychites* beds (*neuquensis* Subzone). *Oosterella* is a predominantly late Valanginian ammonite that just extended into the earliest Hauterivian.

6. Regional significance

Division of the Agrio Formation sequence into 16 successive zonal/subzonal units provides the most detailed biostratigraphy yet achieved for any of the Andean basins of South America. Thus this zonation will provide an important standard for correlating the less well-documented faunas from Chile, Peru and Columbia, which share many taxa in common with the Neuquén Basin.

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