On the Barremian - lower Albian stratigraphy of Colombia

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Key words – stratigraphy, Barremian, Aptian, depositional sequences, Colombia.
The biostratigraphy and sequence stratigraphy of the Barremian deposits, and the biostratigraphy of the Aptian deposits in the Villa de Leyva area in Colombia are briefly described.

Contents

Introduction

The Barremian-Aptian ammmonite species of the Creutzberg Collection described in this volume are derived from the Paja Formation. The Paja Formation was deposited during the Hauterivian and Barremian ages, and during the greater part of the Aptian age. Besides, some lower Albian ammonite species were described belonging to families that also occur in the Aptian strata of Colombia; they are derived from the Tablazo Formation in the Guane-Barichara area and from the Apulo area.

This short description of the stratigraphy is only included to give a rough impression of the stratigraphy of the rocks from which Peter Creutzberg collected his limestone concretions with ammonites. It mainly consists of a short summary of the Barremian and Aptian biostratigraphy as proposed by Patarroyo (1999, 2000a, b) and Etayo-Serna (1979). I have added to it the sequence-stratigraphic interpretation of the Barremian of the Loma La Yesera near Villa de Leyva.

The studied fossils were mainly collected in the Villa de Leyva (Boyacá), Apulo (Cundinamarca), Guane-Galan (Santander) and Vélez-Jesus Maria areas (Santander).

In 1997 Hoedemaeker measured two sections through the Barremian strata in the Villa de Leyva area and interpreted the sequence stratigraphy of the Barremian in Colombia. In 1998 a group of geologists and geological assistants of the Nationaal Natuurhistorisch Museum 'Naturalis' (NNM) in Leiden, The Netherlands, under the leadership of Hoedemaeker, collected many ammonites *in situ* from the Hauterivian and Barremian strata in the Villa de Leyva area; they also measured a section through the Hauterivian. The ammonites were taken to NNM for identification. However, at

the same time Pedro Patarroyo Gama from Colombia wrote his dissertation on Barremian ammonites and their biostratigraphy (Patarroyo, 1999, 2000a, b). He collected many more ammonites *in situ* in the Villa de Leyva area and published the stratigraphic logs of the same Barremian sections as measured by the Dutch geologists. The columns constructed by Hoedemaeker matched in detail those of Patarroyo (1999, 2000a, b) and Patarroyo's biostratigraphy was intergrated with Hoedemaeker's sequence stratigraphy.

In the present paper, the Barremian biostratigraphy of Patarroyo is combined with the Barremian sequence stratigraphy of Hoedemaeker. On account of this combination, a good correlation could be made with European biostratigraphy and sequence stratigraphy. I followed the subdivision of the Aptian of Etayo-Serna (1979), but added a new, lower Aptian assemblage-zone defined by the presence of *Prochelonicerasalbrechtiaustriae* and *Cheloniceras cornuelianum*.

Barremian

In the Villa de Leyva region, the Paja Formation mainly consists of black, slightly calcareous shales, and comprises the Hauterivian and Barremian stages, and at least the major part of the Aptian Stage. The black shales contain an appreciable amount of organic carbon. The Colombian Basin was an anoxic marine basin during these times. Benthic fauna is very rare. Only in a few limestone intercalations some thin-shelled bivalves were found. The Paja Formation has been subdivided into three members; the 'Lutitas Negras Inferiores', 'Arcillolitas Abigarradas', and the 'Arcillolitas con Nodulos Huecos' members. The 'Lutitas Negras Inferiores' Member is Hauterivian (340 m; Etayo-Serna, 1968a, b), and consists of black (= negro) shale with a few calcareous siltstone and limestone intercalations. When weathered the shales have a yellow colour and fall apart into long angular pencils.

The overlying 'Arcillolitas Abigarradas' Member (480 m thick; Etayo-Serna, 1968a, b; 425 m thick: Mann *et al.*, 1994) is characterized by the presence of many micritic and calcarenitic limestone beds, always with hematite flakes. In thin sections the micrite or calcarenite is often cloudy with degraded organic material, algal mats, algal pellets and plant debris, also with patches of gypsum and gypsum-filled cracks; the micrite is often recrystallized into sparite. These hard beds generally show a reddish hue, are on the average 0.3 m thick (0.05-1.2 m), and are intercalated within black, slightly silty shales, which may show laminations. The black shale interbeds between the hard intercalations are on the average 4 m thick (0.002-6 m); gypsum is abundant. The variegated (= abigarradas) colours refer to the vivid red, yellow, orange and green colours of some of the many limestone beds, supposedly due to subaerial weathering when the sea had temporarily retreated. At some levels white shale layers are intercalated amidst the black silty shales. They consist of halloysite, a mineral that may originate as a conversion product of volcanic ashes. If so, the ashes may be derived from volcanoes related to the subduction of the crust of the Pacific Ocean below the South American continent. The lowest halloysite layer in the Villa de Leyva area is situated in the uppermost Hauterivian. This was the time that the vulcanism of the geotectonic cycle of the Andes developed (Etayo-Serna *et al.*, 1976, p. 243). Also, a layer of cannel coal (algal coal) is present in the upper Barremian (sequence boundary Ba4 in the section

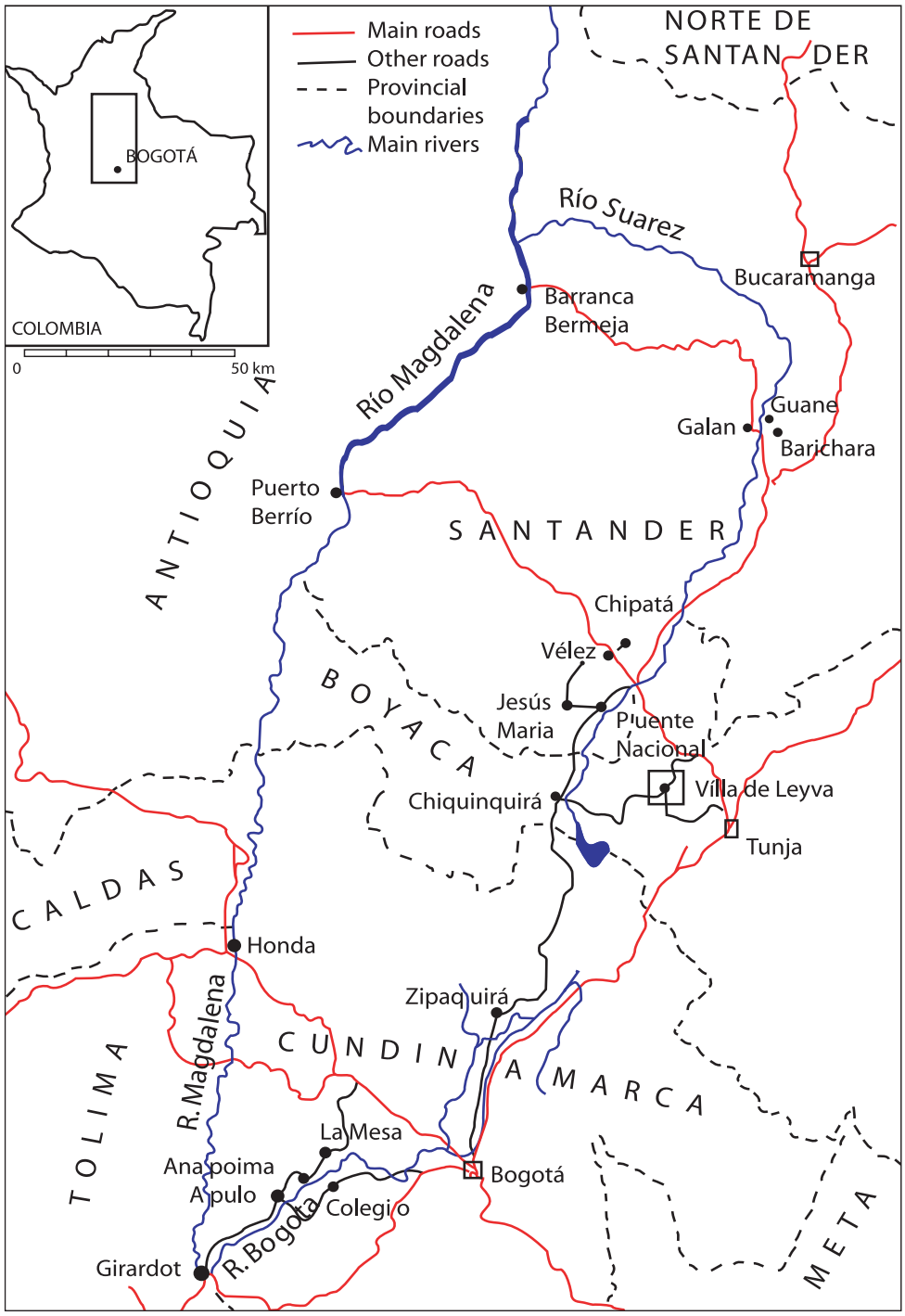


Fig. 1. Map of the region of Colombia from which P. Creutzberg collected the fossils described herein.

along the road from Sáchica to Puente Samacá), indicating paralic conditions near the end of a depositional sequence, which ends with a thick calcareous bed on top of the coal. In the Barremian and lower Aptian there are several thin gypsum layers, generally on top or at the bottom of the limestone beds. The gypsum is disseminated along the shale partings and seems to be scattered through the shales. The thick black crystalline layers that generally occur on top of several limestone beds are remarkable. They occur in the Arcillolitas Abigarradas Member and consist of long, thin, black calcite crystals of the equal length, which have grown poikilitically around the clay flakes of the clay on top of or below the limestone bed. These long, parallel calcite fibres grow perpendicular to the bedding plane. In a few cases these calcite-fibre layers may build continuous beds up to 0.2 m thickness of their own. Forero-Onofre & Sarmiento-Rojas (1985) compared them with the upper surfaces of recent algal mats developed in the intertidal flats of Abu Dhabi.

It is difficult to assess the depth of the anoxic basin. The anoxic shales with ammonites, fishes, pliosaurs and ichthyosaurs do suppose a certain depth, but the vivid colours of several beds, the presence of cannel coal, plant remains and the considerable amount of gypsum (formerly exploited by local farmers) suggests extreme shallowness. I agree with the idea of Forero-Onofre & Sarmiento-Rojas (1985) of intertidal flats; the large number of ammonites and the presence of ichthyosaurs must then be explained as drifted ashore. The vividly coloured crusts suggest temporal emergence. The ammonite fauna is typical for shallow seas.

The Arcillolitas Abigarradas Member also contains many calcareous concretions consisting of black crystalline calcite; sometimes they produce a slight fetid bituminous smell. Some of them enclose undeformed fossils, which form the main part of the Creutzberg collection. On account of the collected ammonites, the Barremian stage begins at the base of the 'Arcillolitas Abigarradas' Member. It became apparent that in the Loma La Yesera, the name of a hill about 3 km southsouthwest of the village of Villa de Leyva, only the lower 127 m of the Arcillolitas Abigarradas Member are Barremian. Along the road from Sáchica to Puente Samacá, the Barremian stage presumably has a thickness of 155 m on account of indecisive ammonite occurrences (Patarroyo, 1999, 2000a, b) and sequence-stratigraphic considerations. The remainder of the 'Arcillolitas Abigarradas' Member comprises the main part of the Aptian stage.

Patarroyo (1999, 2000a, b) distinguished five ammonite zones in the Barremian, *viz.* a basal *Psilotissotia colombiana* Zone, *Nicklesia pulchella* Zone, *Pulchellia galeata* Zone, *Heinzia (Gerhardtia) veleziensis* Zone and *Colchidites breistrofferi* Zone at the top. Because of the presence of several species of *Pseudocrioceras* in the Creutzberg collection, it may be possible to introduce an uppermost assemblage-zone of *Pseudocrioceras* on top of the *C. breistrofferi* Zone, as in the Mediterranean Province. The specimens of *Pseudocrioceras* of the Creutzberg collection were, however, not found *in situ*. On account of this zonation, a rough correlation can be set up between Colombia and Europe.

Barremian sequence stratigraphy

The above-mentioned rough correlation could be made more precise by taking into account the sequence stratigraphic interpretation of the Colombian Barremian of Hoedemaeker (Figs. 1-3). It was difficult to do sequence stratigraphy in the rather

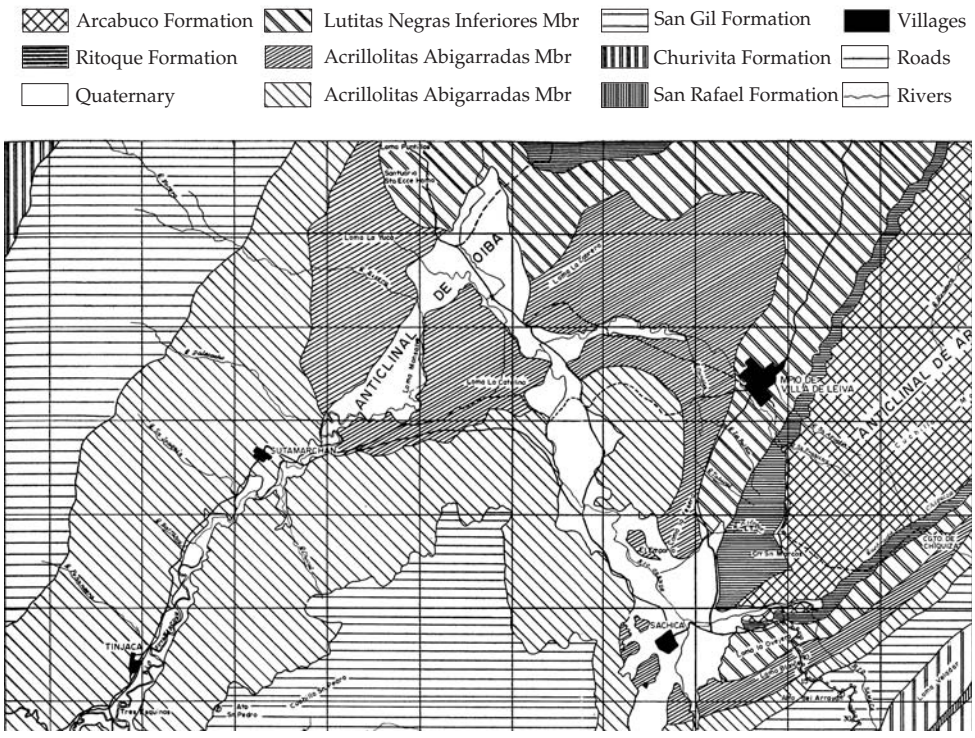
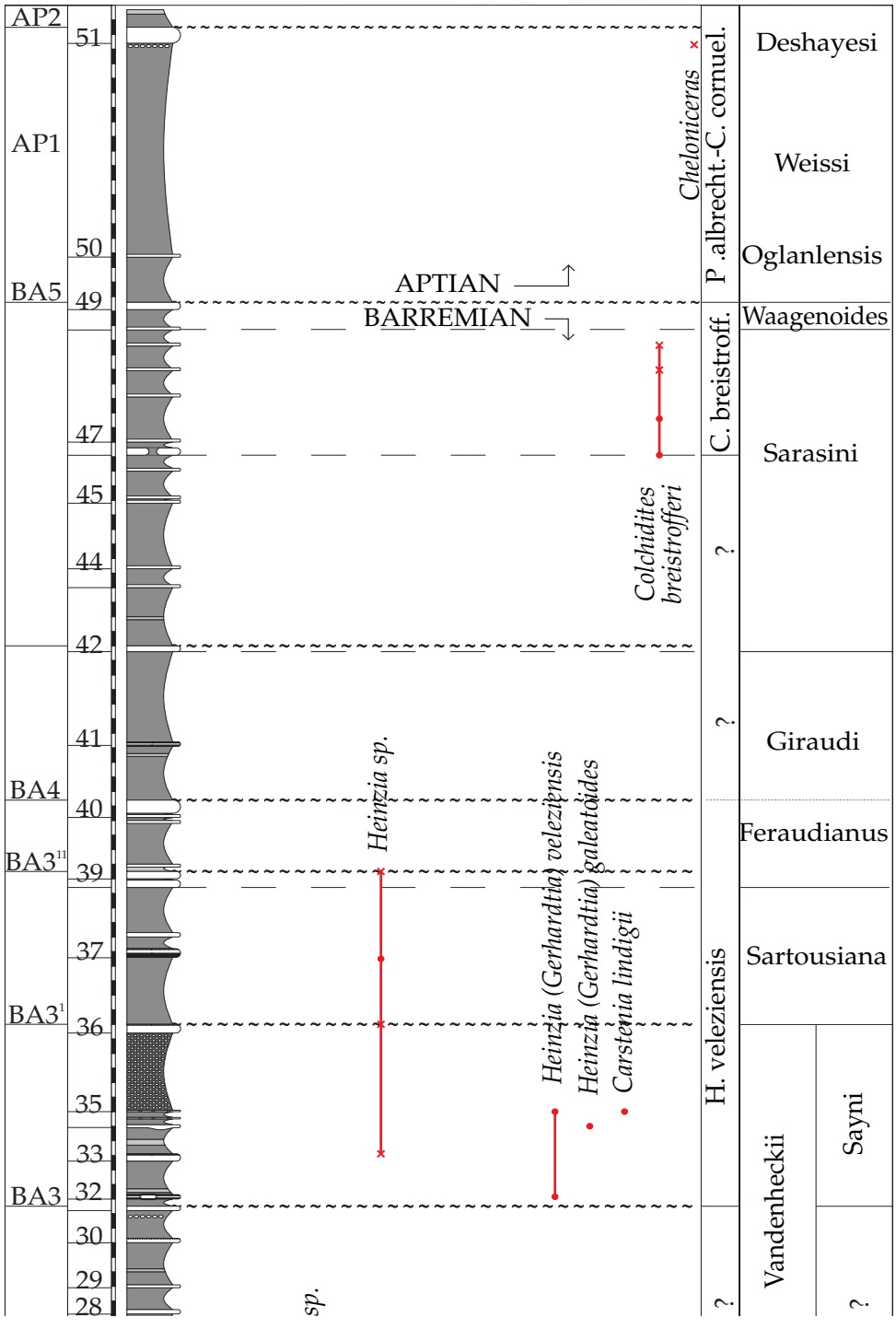


Fig. 2. Geological map of the area around Villa de Leyva.

monotonous Barremian succession of the Loma La Yesera. On account of ammonites, the thickness of the Barremian stage was clear. I knew from the sequence-stratigraphic analysis of the Río Argos succession in southeast Spain (Hoedemaeker & Leereveld, 1995) that the Barremian has at least eight sequences, but it was at first unclear how to recognize them. Later (Hoedemaeker, 2002; Hoedemaeker & Herngreen, 2003) it became clear that the Barremian stage comprises at least ten depositional sequences, but, looking from a distance to the silhouette of the hill, it struck me that there were about eight thick beds protruding a little from the otherwise smooth curve of the hill. I realized that this could be the expression of sequence stratigraphy. On closer inspection it appeared that most thick beds either consist of homogeneous or cloudy to smeary micrite, interpreted as ghosts of algal mats, often recrystallized into sparite, or of well-sorted, recrystallized calcarenite with cross stratification. Between every two thick protruding beds, the distances between the limestone intercalations diminish in the upward direction, and consequently also the thicknesses of the shale interbeds. The limestone intercalations themselves also become, on the average, thicker in the upward direction and may bear red colours; the amount of shale is greater on top of the thick protruding beds than below them.

The sucessions between the thick, slightly protruding sandstone beds could, therefore, be interpreted as shallowing upward successions, and, consequently, as the highstand systems tracts of depositional sequences. The shale-limestone couplets are


AP2
AP1
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APTIAN
BARREMIAN
Cheloniceras
Colchidites breistrofferi
Heinzia sp.
Heinzia (Gerhardtia) velezensis
Heinzia (Gerhardtia) galeatoides
Carstenia lindigii
sp.
P .albrecht.-C. cornuel.
C. breistroff.
H. veleziensis
?
?
?
Deshayesi
Weissi
Oglanlensis
Waagenoides
Sarasini
Giraudi
Feraudianus
Sartousiana
Vandenheckii
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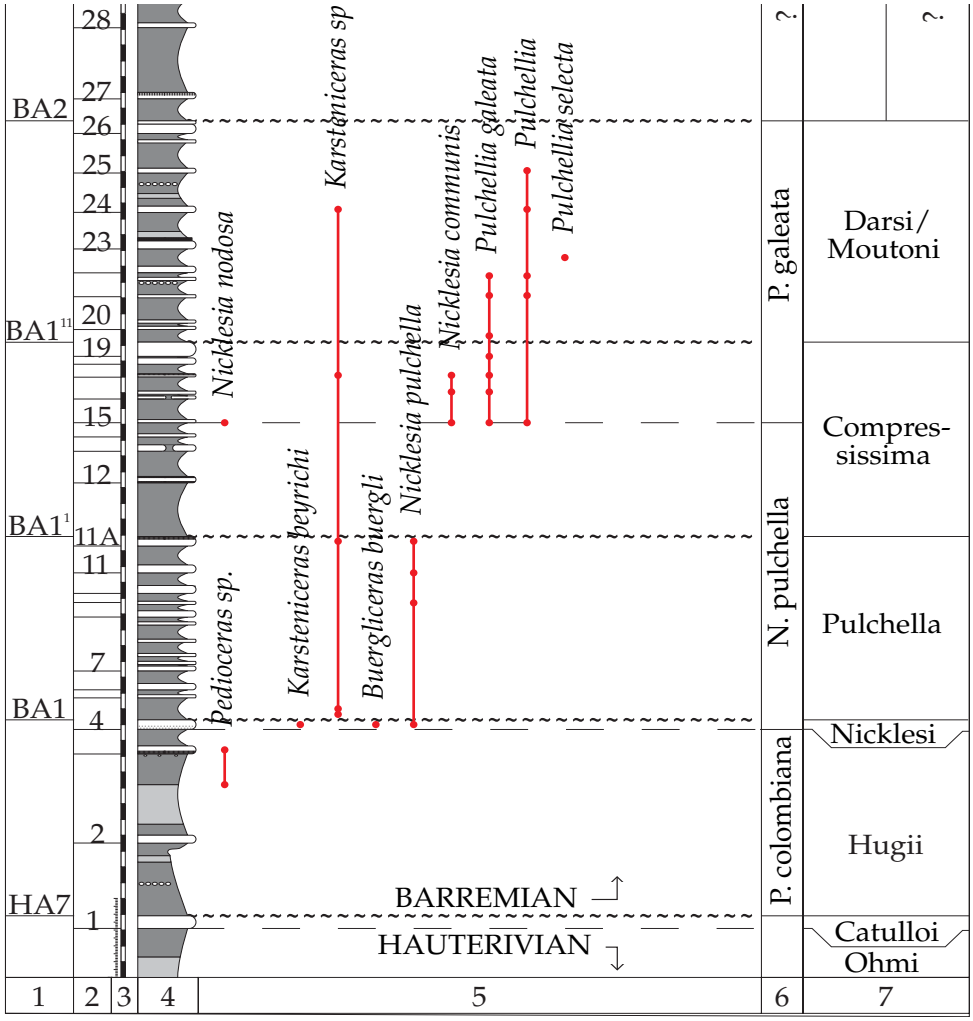

Fig. 3. Stratigraphic log of section of the Loma La Yesera (Villa de Leyva, Boyacá, Colombia) showing the sequence-stratigraphic interpretation, and the correlation of the Barremian strata of Colombia and southern Europe. Column 1: depositional sequences. Column 2: bed numbers. Column 3: thickness in metres. Column 4: lithological column. Legend: black = black shales; grey = halloysite layers; white = limestone beds; wavy lines = hiatuses (= missing lowstand systems tracts); P. albrecht.–C. cornuel. = *Procheloniceras albrechtiaustriae – Cheloniceras cornuelianum* assemblage Zone. Column 5: ammonite ranges according to Patarroyo (1999, 2000a, b) supplemented by data from the NNM group. Column 6: Colombian ammonite zones proposed by Patarroyo (1999, 2000a, b). Column 7: southern European ammonite zones (Hoedemaeker *et al.*, 2002).

interpreted as parasequences in which the algal limestone intercalations represent the upper parts, because they represent the shallowest parts (Forero-Onofre & Sarmiento-Rojas, 1985) of the shale-limestone couplets. The maximum flooding surfaces, which are the most offshore parts of the depositional sequences, are situated within the most

shaly intervals of the successions; the latter are generally situated directly above the thick protruding beds; the protruding algal limestone beds, which are the most nearshore parts of the succession, generally have a red colour and were interpreted as the highest parts of the highstand systems tracts. They contain a few bivalves and are the only beds in which rare benthic fossils occur.

So the sequence stratigraphy of the Barremian strata in the Villa de Leyva basin can be typified as a stacking of mainly prograding highstand systems tracts. The lowstand systems tracts do not appear to have been developed; each sequence begins at, or just below, the maximum flooding interval. The sequence boundaries were interpreted as situated directly above the thick protruding beds. In a few cases the highest parts of the transgressive systems tracts seem to be present, as the maximum flooding surfaces were separated from the protruding top highstand beds of the underlying sequence by a few thin, marly limestone beds. During most periods of sea-level lowstands the sediments were emerged or bypassing. Only in one instance was there, apparently, a long-lasting emergence; sequence boundary Ba1''. The absence of the lowstand systems tracts can be explained by the extreme shallowness of the Barremian sea near Villa de Leyva. Only in deeper basins are the lowstand systems tracts well developed.

The ammonite ranges published by Patarroyo (1999, 2000a, b) allowed a correlation with the ammonite biostratigraphy and, consequently, the sequence stratigraphy of southeast Spain and southeast France (Jaquin, 1993; Hoedemaeker & Leereveld, 1995; Hardenbol *et al*., 1998; Arnaud *et al*., 1998; Hoedemaeker, 1995, 1998, 1999, 2002; Hoedemaeker & Herngreen, 2003). It was immediately possible to identify and correlate six of the Colombian sequence boundaries with those in Spain and France. After this, the intermediate sequence boundaries could be interpolated without many problems, even the two new Barremian sequence boundaries that were introduced later by Hoedemaeker & Herngreen (2003), who defined ten sequences in the Barremian. This suggests that the correlation is fairly correct.

The following biostratigraphic correlation can be made (Fig. 3). In France *Psilotissotia colombiana* occurs in the Hugii Zone, sequence Ha7. In France, as well as in Colombia, the genus *Nicklesia* begins its range in the highest part of sequence Ha7. In France the last species of the genus *Pulchellia*, *P. caicedi,* occurs in sequence Ba1'' (Vermeulen, 1996, 1998). In Colombia the last *Pulchellia, viz. P. galeata, P. selecta* and *P. fasciata,* also occur in this sequence (Patarroyo 1999, 2000a, b). In France as well as in Colombia *Pulchellia communis* occurs in the highstand systems tract of sequence Ba1'. It should be noted that Patarroyo included *Pulchellia communis* in the genus *Nicklesia*. The *Nicklesia-Pulchellia* lineage does not overlap with *Heinzia* in Colombia (Patarroyo, 1999, 2000a, b), nor in Europe. In Spain (Río Argos succession; Hoedemaeker & Leereveld, 1995), *Heinzia* begins its range together with *Ancyloceras vandenheckii* in the transgressive systems tract of sequence Ba2. In France, *A. vandenheckii* also begins its range in the transgressive systems tract of sequence Ba2, but the first *Heinzia* appears, like in Colombia, in sequence Ba3. In Spain, the last *Heinzia* occurs in the Feraudianus Zone. In France as well as in Colombia *Colchidites* occurs in sequence Ba4'.

The interpreted positions of the sequence boundaries in Colombia and Spain enables a more precise correlation between the ammonite zones of Patarroyo (1999, 2000a, b) (Fig. 3, column 6) and the standard ammonite zones in the Mediterranean

region (Hoedemaeker *et al*., 2002) (Fig. 3, column 7) than was hitherto possible. It also supports the idea that the sequences in South America and Europe are precisely time equivalent, and that sequences are incited by global sea-level fluctuations.

Aptian

Along the road from Sáchica to Puente Samacá, the Aptian part of the Paja Formation can easily be measured and is about 400 m thick (380 m according to Mann *et al*., 1994, and 425 m according to Etayo-Serna, 1968a, b). The Aptian part of the 'Arcillolitas Abigarradas' Member consists of black shales and limestone intercalations. However, the amount of intercalations is appreciably less than in the Barremian part of the Arcillolitas Abigarradas Member. Gypsum layers are still present.

The third member of the Paja Formation, the 'Arcillolitas con nodulos huecos' Member (80 m thick: Etayo-Serna, 1968a, b; 90 m thick: Mann *et al*. 1994), consists of black shales and contains hollow (= huecos) septarian concretions. It has probably a middle to late Aptian age because of the presence of the late Aptian *Colombiceras riedeli* Cantú-Chapa in the overlying member.

In the Villa de Leyva area, the Paja Formation is overlain by the 'San Gil' Formation, which conists of sandy shales, limestones and sandstones. The lower member of the 'San Gil' Formation begins with a sandy shale (= part A, 140 m thick), which is followed by shaly limestones (= part B), sandstones (= part C) and again sandy shales (= part D), although less sandy than part A. The sandy shales of part A yielded *Colombiceras riedeli* Cantu-Chapa and *Eodouvilleiceras*; the limestones of part B yielded *Colombiceras obliquum* Riedel (Etayo-Serna, 1968a, b); these parts may be assigned to the upper Aptian. The totality of Part B has been assigned to the Albian by Etayo-Serna (1968a, b), but later (Etayo-Serna, 1979) he reassigned only the upper part of Part B above the level of *C. obliquum* to the Albian, though still without demonstrable reasons.

In this article, the Aptian stage is divided into three substages, the lower, middle, and upper Aptian, corresponding to the Bedoulian, Gargasian and Clansayesian substages, respectively. However, owing to the imprecise knowledge of the stratigraphic level from which the ammonites are derived in Colombia, it is difficult to separate the upper Aptian from the middle Aptian. Therefore, these two substages are united in this bundle and referred to as 'middle/upper' Aptian.

Etayo-Serna (1979) was the first who endeavoured to produce a biostratigraphy for the Aptian of Colombia. In fact he only produced a rough biostratigraphy for the middle/upper Aptian.

A. His first and oldest biostratigraphic unit he called *Dufrenoyia sanctorum - Stonyanowiceras treffryanus* assemblage-zone which is mainly characterized by the presence of *Dufrenoyia, Epicheloniceras, Gargasiceras, Vectisites, Riedelites, and Colombiceras.* This assemblage zone would straddle the lower-middle Aptian boundary as proposed by the IUGS Lower Cretaceous Ammonite Working Group (Hoedemaeker *et al*., 2002), because the genus *Dufrenoya* is restricted to the upper part of the lower Aptian (= Bedoulian Substage). Etayo-Serna's first assemblage zone thus covers the main part of the Gargasian substage and the uppermost part of the Bedoulian substage.

B. Etayo-Serna (1979) called his second biostratigraphic unit *Parahoplites*(?) *hubachi - Acanthohoplites leptoceratiforme* assemblage-zone, which is mainly characterized by *Acanthohoplites* and *Parahoplites*. It would incorporate the higher part of the Gargasian and probably a part of the Clansayesian.

C. The third and youngest zone was named *Douvilleiceras solitae - Neodeshayesites columbianus* assemblage-zone, which Etayo-Serna (1979) considered to be of early Albian age. It is characterized by the presence of *Neodeshayesites* and *Eodouvilleiceras*, but also by the first *Douvilleiceras*. However, this age should be questioned.
   1. With respect to the time range of *Neodeshayesites*, Etayo-Serna (1968b) recorded *Colombiceras alexandrinum* Bürgl, *non* d'Orbigny (= *Neodeshayesites buergli* Bogdanova & Hoedemaeker, 2004) from the upper part of the Arcillolitas Abigarradas Member (part E), which would indicate a middle to late Aptian age.
   2. In Venezuela *Neodeshayesites* was reported only from the Machiques Formation, which was inferred to be Aptian on account of included microfossils. On the Venezuelan profiles figured by Renz (1982), the Machiques Formation is considered to have a middle/late Aptian age.
   3. Creutzberg indicates the presence of beds with "*Deshayesites*" (= *Neodeshayesites*) and *Epicheloniceras* in septarian concretions probably derived from the Member 'Arcillolitas con nodulos huecos' above beds with *Dufrenoyia* in the hill called Loma Blanca; this would indicate a middle/late Aptian age for the beds with *Neodeshayesites*. Moreover, he often recorded findings of *Neodeshayesites* only in relation with Aptian ammonites.
   4. Finally, however, Etayo-Serna (1979, p. 10) recorded the association of *Neodeshayesites columbianus* with *Eodouvilleiceras pedrocarvajali* and *Trochleiceras juliverti* from the sixth interval of the Cerro Bejucal reference section of the Capotes Member. According to Etayo-Serna (1979, p. 57), *E. pedrocarvajali* has been reported by Bürgl (1961) to concur with *Douvilleiceras* and the sixth interval should, therefore, have an Albian age. Moreover, the presence of *Douvilleiceras tarapacaense* 25 m below a level with *Neodeshayesites columbianus*, in the reference section of the Capotes Member west of the village Tarapaca, indicates an Albian age. Also, Creutzberg found many specimens of *Neodeshayesites* in association with *Douvilleiceras* and *Prolyelliceras* in the Anapoima-Apulo and Guane-Barichara areas. However, as mentioned above, *Eodouvilleiceras* has been reported also from upper Aptian strata (Lower San Gil Formation, part A). '*Douvilleiceras' clansayesiense* Jacob, 1905, *non* 1906, from the upper Aptian Clansayesian Substage in France, may also belong to *Eodouvilleiceras* (Casey, 1961, p. 191), because it shows the onset of a splitting of the last ventrolateral tubercle.

Thus, the ranges of both *Neodeshayesites* and *Eodouvilleiceras* probably straddle the Aptian-Albian boundary. Therefore, the third zone of Etayo-Serna probably just straddles the Aptian-Albian boundary, and comprises the uppermost part of the Aptian and the lower Albian.

D. Although not incorporated in the zones of Etayo-Serna (1979), it is known that lower Aptian (Bedoulian) strata are present in the Villa de Leyva area because of the presence of several species of *Procheloniceras* and *Cheloniceras.* Therefore, a preliminary assemblage-zone of '*Procheloniceras albrechtiaustriae - Cheloniceras cornuelianum*' may be added to the three assemblage zones of Etayo-Serna (1979).

Etayo-Serna (1979, p. 13) defined the base of his *Dufrenoyia sanctorum - Stoyanowiceras treffryanus* assemblage-zone at the top of the white argillaceous bed with *Procheloniceras* cf. *albrechtiaustriae* (station 10 at km 28 on the road from Sáchica to Puente Samacá). This should also be the top of the lower Aptian assemblage-zone here proposed. The base cannot be defined exactly, but should be situated above the top of the uppermost Barremian *Pseudocrioceras waagenoides* zone. Along the Sáchica-Puente Samacá road, the '*Procheloniceras albrechtiaustriae - Cheloniceras cornuelianum*' assemblage-zone has a thickness of about 70 m and would comprise the near totality of the lower Aptian.

It should be noted that the genus *Deshayesites* is not present in Colombia, which renders the precise determination of the base of the Aptian Stage very difficult. It can only be done with sequence stratigraphy (top lowstand surface of sequence Ba5) or, in the future, with magnetostratigraphy (base of chron M0).

Lowermost Albian

There are two main areas where Creutzberg collected ammonites from the lowest Albian. These are in the Guane-Barichara and Anapoima-Apulo areas. Creutzberg collected many specimens of *Douvilleiceras* and *Neodeshayesites* from the Barichara area, where the dark shales of the 'Paja Formation' are concordantly overlain by the 'Tablazo' Formation, consisting of limestones and shales of Albian age.

In the Anapoima-Apulo area the lower part of the Albian yielded many specimens of *Douvilleiceras, Prolyelliceras* and *Neodeshayesites columbianus*. It is followed by beds that contain many specimens of *Oxytropidoceras* and *Venezoliceras,* also collected by Creutzberg, but not described in this bundle.

Conclusions

It appears that the section of the Loma La Yesera shows the best sequence-stratigraphic signal and can for that reason be correlated with the European stratotype of the Barremian Stage with greater precision than was hitherto possible. On account of the presence of *Pseudocrioceras* in Colombia, an assemblage zone of *Pseudocrioceras* can be inferred at the top of the Barremian, which probably occupies the upper part of the last highstand systems tract of the Barremian.

As to Aptian stratigraphy, Creutzberg's ammonites show that the time equivalents of most standard Mediterranean ammonite biozones of the lower, middle and upper Aptian appear to be present, but that the outcrops, thicknesses and geographic extent of their rock bodies could not be determined, because only a few ammonites of the Creutzberg collection have been sampled *in situ*. So, their stratigraphic level remains unknown. In addition to the two middle/upper Aptian assemblage-zones introduced by Etayo-Serna (1979), a new, lower Aptian assemblage-zone is introduced here, *viz.* the *Procheloniceras albrechtiaustriae-Cheloniceras cornuelianum* assemblage-zone characterized by the genera *Procheloniceras* and *Cheloniceras*.

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