Lower Cretaceous Ammonite Diversity at a New Location in the Rosa Blanca Formation

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Ammonites have been an important fossil group for the fields of evolution, paleoceanography, biostratigraphy, and paleoecology. Its diversity, its presence in a wide variety of marine environments and its easily conserved shells explain its usefulness in both paleontological and geological studies. Colombia is a country with a high occurrence of fossil ammonoids, even so, there are a very limited number of reports regarding its diversity and paleoecology. The purpose of this project is to identify the diversity of Cretaceous ammonites in the Rosa Blanca Formation, in a particular rock layer with a high concentration of these fossils at La Virgen West locality, in the town of Zapatoca, Santander. For this, fossil samples were collected, to later be analyzed and classified according to their morphological characteristics. Subsequently, four morphotypes were identified that match with known taxa described in the consulted literature, and finally a short discussion on the diversity of this layer, changes exhibited by some of the taxa along ontogeny and implications for future paleobiogeographic studies are presented.

Key words: Ammonites, Cretaceous, taxonomic identification, diversity, ontogeny

Introduction:

Mollusks are a group of invertebrates that exhibit an extensive morphological variation, which are usually protected by a shell made of calcium carbonate. They have inhabited for millions of years the vast majority of aquatic and terrestrial environments (Ponder & Lindberg, 2008). The fossil record of this marine group is considered abundant and well preserved, both due to their high diversity and quantity of individuals in the populations. The ammonoids had a particular locomotion system, similar to the current system used by the nautilids (Naglik et al, 2015). The shell of these current organisms fulfills the function of buoyancy, which allows the nautilus to submerge or ascend at will, controlling the density and volume of the liquid within its different chambers in the shell. Similar to nautilids, the ammonoid shell is made up of two parts: the chamber and the fragmochorus (responsible for buoyancy) (Jacobs et al 1994). The fossilization process of these shells is varied, and they can be preserved in different ways, either in aragonite or recrystallized in a more stable mineral such as calcite, both being carbonates ($CaCO_3$) minerals. Another type of conservation is in the form of internal or external molds which capture the shape

of the organism in a sediment that ussually becomes limestone rock via lithification (González-Arreola et al., 2014). All these types of fossilization allow the taxonomic identification of ammonites since they preserve the essential characteristics to establish the different genera and species (see Fig. 1).

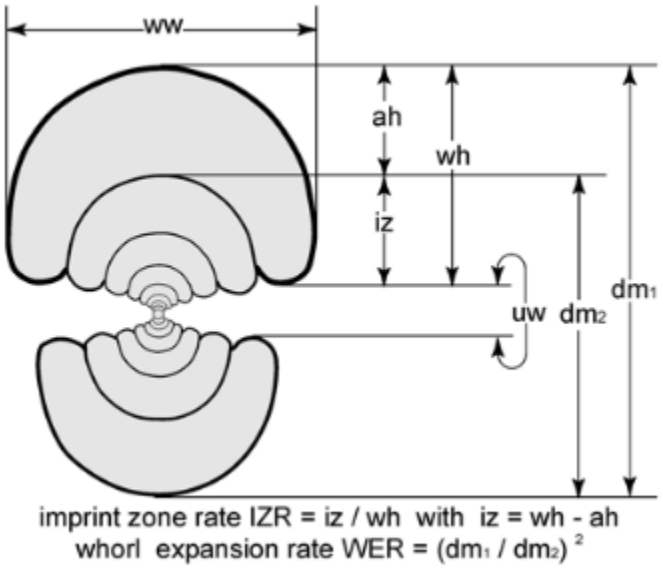

Fig. 1. Ammonite shell parameters overview. Where (ww) is whorl width, (wh) is whorl height, (wb) is whorl breadth and (uw) is umbilical width, (iz) is imprint zone, (ah) is aperture height and (dm) is diameter (Klug, Zatón & Parent, 2015).

An important characteristic that allows the identification of different species is the ornamentation. The type of ornamentation depends on the specific characteristics of each species or genus, for which the ornamentation as such is very varied (Kerr & Kelly, 2015). The ribs are an ideal type of ornamentation for taxonomic identification. These are located on the sides of the shell and present different patterns, they can be primary or secondary depending on their shape and grouping. Another element of ornamentation is the protuberances of the shell called tubercles, these are located in different areas of the shell. Another feature that is also preserved is the suture line. Suture lines are highly complex traces found in the shell and extend from the center to the inner walls as size increases (Inoue & Kondo, 2016). These lines have different patterns, which become more complex as these organisms diversify. On the other hand, one of the characteristics to take into account in taxonomic identification is sexual dimorphism, as sizes may vary between genders.

This characteristic is important since the morphology in the juvenile and adult stages is different. These dimorphisms are known as a micro-shell for males and a macro-shell for females, which tend to be larger. The micro-shells are characterized by being evolving shells with a very marked ornamentation, while the macro-shells are involute forms with a less marked ornamentation as in the micro-shell (Klug et al, 2015).

The ammonites appeared during the Devonian (Paleozoic Era), and the last species vanised from the oceans during the Cretaceous-Paleogene mass extinction (K-Pg event) (Mcgowan & Smith, 2007). At one point, this group of invertebrate animals was one of the most dominant in marine environments, so well-preserved fossils can be found around the world. Its dominance brought with it a great diversity of species with unique and specific characteristics adapted to their environment, possible sexual selection and sexual dimorphism, among others (Kennedy & Cobban, 1976). Due to their high diversity, the fossils found have many functions including the identification of stratigraphic units that allow establishing chronological equivalences in time thanks to the type of ammonites found in certain rocky bodies calibrated with other geologic time proxies, as for example, radiometric age (absolute time). This means that the plurality of individuals in the past, allows us to infer the conditions in which these organisms lived, but we still need to know more about their biodiversity in which they were found. In Colombia there are a large number of marine rock sequences and thanks to its geological past it is possible to find a high occurrence of ammonites in various regions of the country. One of the first to describe the richness of ammonites in Colombia was the geologist and paleontologist Fernando Etayo Serna and his work with ammonites has generated an increase in the knowledge of Colombian ammonites.

The Cretaceous was a period of time part of the Mesozoic Era, the Cretaceous is divided into Upper and Lower . The Lower Cretaceous is composed of several ages/stages, one of these is the Valanginian, which occurred between 139.8 Ma to 132.9 Ma. Regarding Colombia and its ammonites, the knowledge of this age is quite limited since it is believed that the South American Plate generated movements that changed the paleoceanographic conditions and therefore the living conditions of the organisms that inhabited northern South America (Etayo-Serna & Guzmán - Ospitia, 2019). This prevents making connections and correlations with other regions. This is why

a new fieldwork in Zapatoca, Santander in the Rosa Blanca Formation is very promising in terms of filling a bit of the knowledge gap presented. The lowermost formation of the Palmira, series referred to as the "Rosa Blanca" Formation, is 412 meters thick and consists predominantly of massive bedded dark gray limestones and marls grading into black thin bedded bituminous limestones and limy shales in the upper 100 m and into black thin bedded bituminous limestone in the bottom 50 m (Etayo-Serna & Guzmán-Ospitia, 2019). In recent years the Grupo de Investigación en Paleontología Neotropical Tradicional y Molecular (PaleoNeo) of the Universidad del Rosario has led an continuos fieldwork activites at the Zapatoca region, particularly in the La Virgen West locality, Carrizal Member of the Rosa Blanca Formation, collecting a large number of fossil ammonites in good condition with a wide range of morphological variation that could indicate several species and genera concentrated in a single bed. With the aforementioned, this study aims to analyze these fossils in order to establish their taxonomy, systematic paleontology, and reconstruct a snapshot of the paleo-diversity of the inner tropical South American sea during part of the Valanginian age.

General objective:

- Study the ammonite fossils from a single bedrock of the Carrizal Member, Rosa Blanca Formation, found in the La Virgen West locality, Zapatoca, Colombia.

Specific objectives:

- Determine the fossils taxonomy based on a detailed study of their morphology, size and variations.
- Establish correlations with the genera or species found in the corresponding time scale, to erect their possibly systematic paleontology.
- Discuss the possible ontogenetic variation observed in the specimens, as well as their implication in terms of paleodiversity of the inner tropical South American sea during part of the Valanginian.

Material & Methods

For this research the fossils were collected in the Rosa Blanca Formation, east of the town of Zapatoca, Santander, La Virgen West locality. They were taken from layers Q to Q0 (following

the stratigraphy of Etayo-Serna & Gumáz-Ospitia, 2019), at coordinates 6º52'24.61"N / 73º14'18.35 ”W. (see Fig. 2).

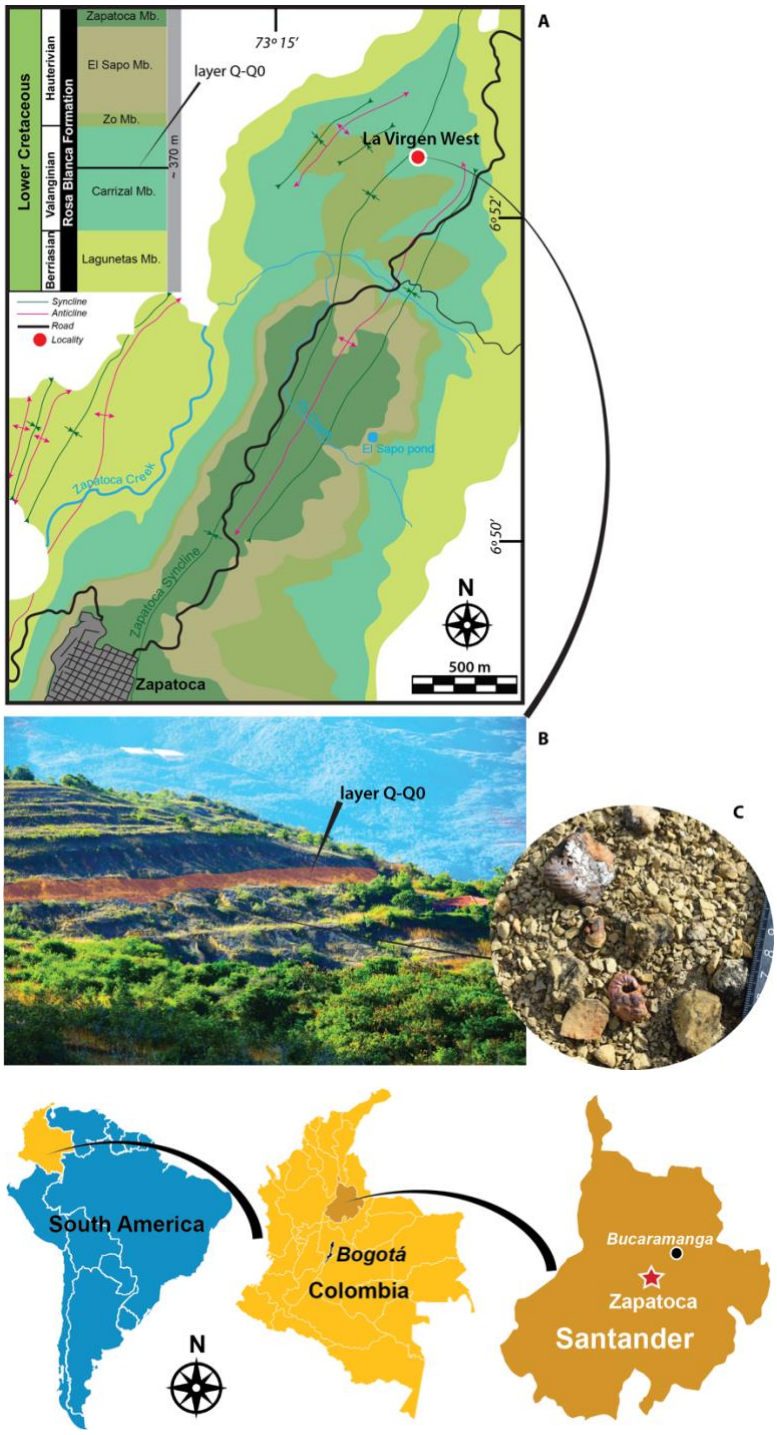

Fig. 2. Geologic and geographic map and details of the La Virgen West locality. A. Geology of the Zapatoca region and the Rosa Blanca Formation divisions following Etayo-Serna & Gúzman-Ospitia (2019). B. Panoramic view of La Virgen West locality indicating the layer Q-Q0 where the fossil ammonites were

collected. C. Look of how the fossil ammonites appear on top of the rock layer. Figure taken and modified from Carrillo-Briceño and Cadena (in press).

Once in the laboratory the 116 fossils were examined with the help of a stereomicroscope (Nikon SMZ-1270) and later the fossils were photographed in great detail at different focal points to obtain better detail of their morphological features. On the other hand, the fossils were examined and grouped into morphotypes according to their basic characteristics such as: size, ornamentation and spaces between ribs, among others. Subsequently, with the NIS-Elements software, at least three images were stacked to generate a single well-focused image. The aforementioned procedure was performed for those fossils small enough to be observed as a whole under the stereoscope. For the larger fossils an EOS 70D Canon camera was used, later the images were edited in Photoshop (version 21.2.1) to highlight the details of the sutures. Once the images were edited, the outline of the fossils and sutures was created as a in tiff file using the Autodesk sketchbook software. Once with these files, another software called ImageJ was used and with the help of machine learning, it will be possible to correlate the vectors of the sutures of the morphotypes with the vectors of the sutures of the possible holotypes of each species. Once the taxonomic process has been carried out, the next step was to determine the biodiversity of the sampled species. For the review literature, the CRAI databases were consulted, where the search terms “ammonites, Cretaceous and diagnosis” were used.

Results

The following is the taxonomic list with the systematic and morphological characteristics of the genera and species of ammonites recognized in La Virgen West locality in Zapatoca, Santander:

Systematic Paleontology

Phyllum *Mollusca* Linnaeus 1754

Class *Cephalopoda* Leach, 1817

Order *Ammonoidea* Zittel, 1884

Superfamily *Perisphinctaceae* Steinmann,1890

Family *Olcostephanidae* Haug, 1910

Subfamily *Olcostephaninae* Haug, 1910

Genus *Olcostephanus* Neumayr, 1875

Fig. 3

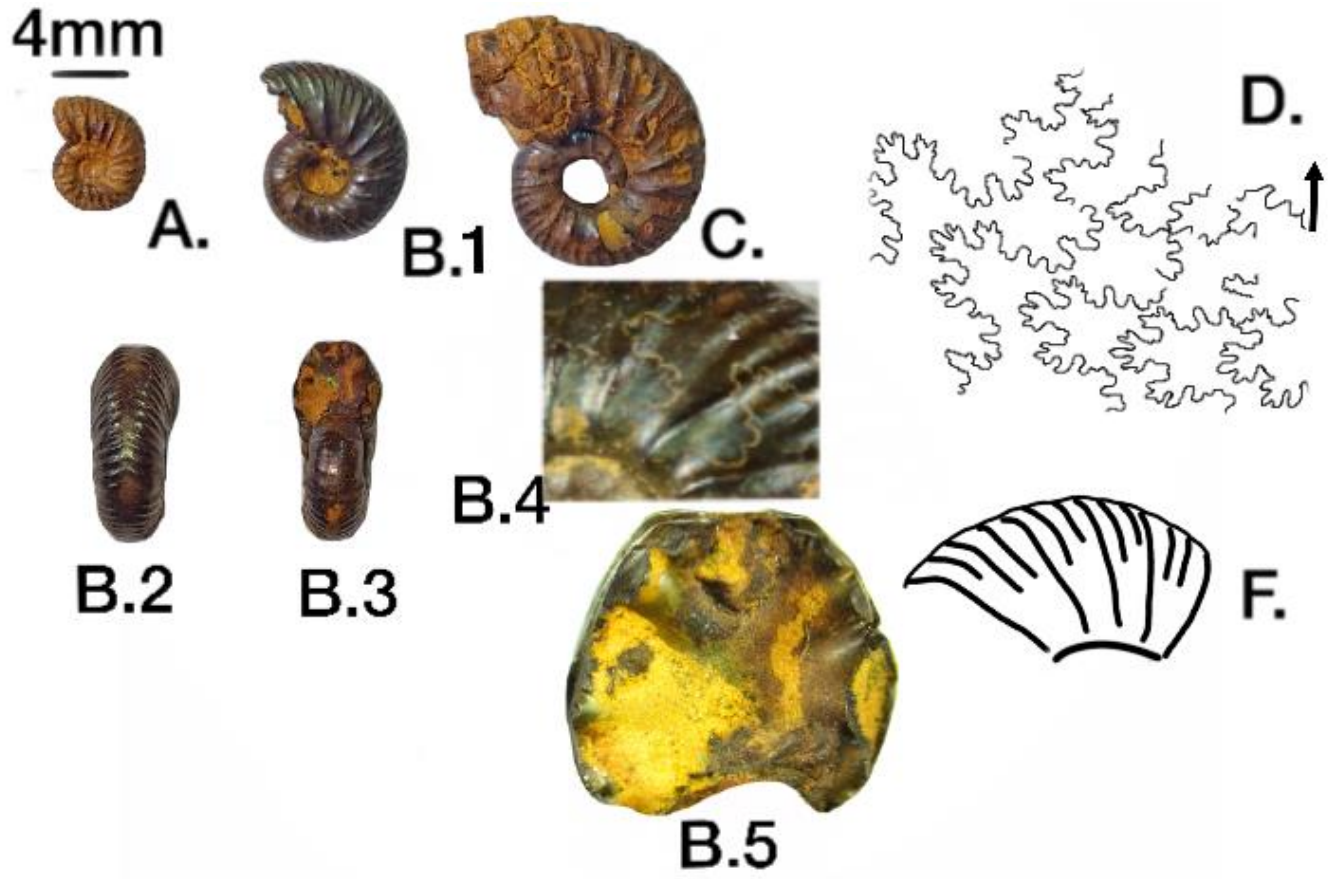

Fig 3. On the left are the *Olcostephanus* sp. specimens with their corresponding characteristics . On the right sutures and the conformation of the ribs. (A) Sample UR-CP-002 in a lateral view. (B.1,B.2,B.3) Samples UR-CP-010, in lateral, dorsal and front view. (B.4,B.5) Samples UR-CP-010 amplified. (C) Sample UR-CP-008 in lateral view . (F) ribs illustration.

Diagnosis

The shell is slightly involute and cadicon with moderately depressed to semicircular whorls. The rursiradiate primary ribs arise near the umbilical seam, becoming progressively prominent on the umbilical slope, and form blister-like tubercles in the upper part of the umbilical region. In each bulla bundles of secondary ribs (2 or 3) are interspersed. The specimens exhibit ammonitic sutures.

Systematic Paleontology

Genus *Saynoceras* Munier-Chalmas, 1893

Saynoceras verrucosum (d'Orbigny, 1841)

Fig. 4

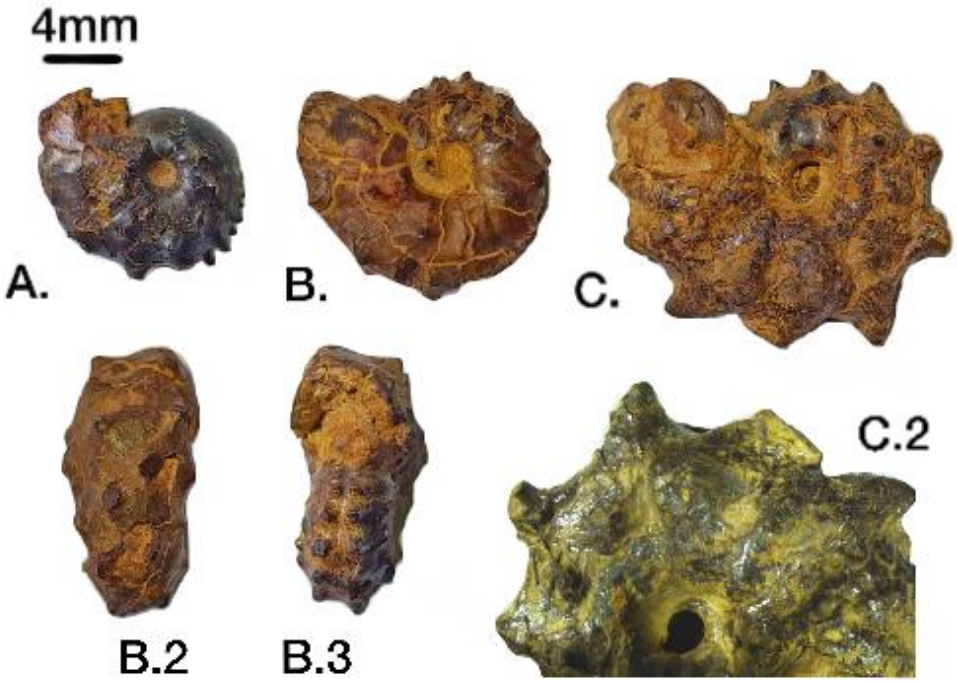

Fig. 4. On the left are the *Saynoceras verrocusum* specimens with their corresponding characteristics. (A) Sample UR-CP-014 in a lateral view. (B) Sample UR-CP-019 in a lateral view. (C) Sample UR-CP-016 in a lateral view. (B.1,B.2,) Samples UR-CP-019, in lateral view. (C.2) Sample UR-CP-016 amplified.

Diagnosis

They are small ammonites (Dmax = 20 mm), the shell is involute, globular and platicone. There are two rows of tubercles that appear to be connected by thin ribs, drawing a very characteristic "zig-zag" pattern (warty stage). Older (bigger in size) specimens have thicker and more pronounced tubers. No sutures can be seen.

Systematic Paleontology

Family Neocomitidae Uhlig 1906

Genus *Neocomites* Uhlig 1906

Species *Neocomites* sp.

Fig.5

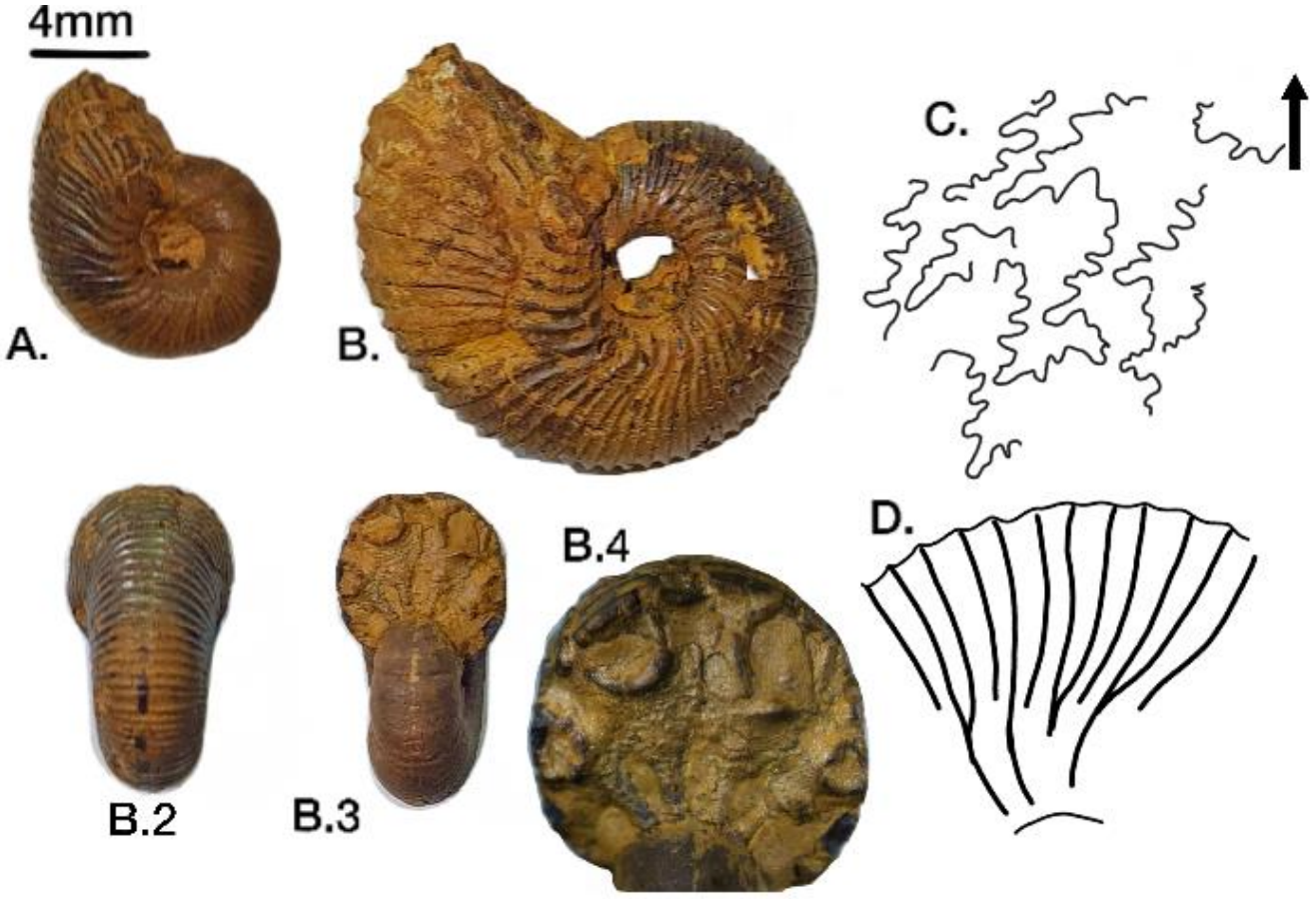

Fig. 5. On the left are the *Neocomites* specimens with their corresponding characteristics. (A) Sample UR-CP-020 in a lateral view. (B) Sample UR-CP-021 in a lateral view. (C) ammonitic suture. (D) ribs illustration.(B.2,B.3,B.4) Sample UR-CP-021 in dorsal, front and amplified view.

Diagnosis.

They have a small shape (Dmax = 16 mm), and very closed turns, prorsiradiate ribs ending at the ventral edge with small marginal tubercles, and stretched, there is no ventral groove since the ribs are united in the dorsal part. They have a glaphycone and faciculate carapace. Specimens exhibit ammonitic sutures.

Systematic Paleontology

Family *Phylloceratidae* Zittle 1884

Subfamily *Phylloceratinae* Zittle *1884*

Genus *Hypophylloceras Salfield 1924*

Fig.6

Fig. 6. On the left are the *Phylloceras* specimens with their corresponding characteristics. . (A) Sample UR-CP-026 in a lateral view. (B) Sample UR-CP-027 in a lateral view. (C) ammonitic suture (D) Sample UR-CP-027 amplified view. (B.2,B.3) Sample UR-CP-027 front and dorsal view.

Diagnosis.

Agaticone and very involute shell; whorl section very ovate; Narrow but prominent navel. Without any ornamentation, the ribs are not identifiable but the ammonitic sutures are best seen due to the lack of ribs.

Table 1. Average size parameters of the ammonites studied in this project. For raw data and full measurement see Appendix.

Taxon	**Shell diameter mm**	**Umbilical width mm**	**Whorl height mm**	**Whorl breadth mm**
Olcostephanus sp.	14.8	3.9	6.0	6.26
Saynoceras verrocusum	14.4	3.13	6.8	7.3
Neocomites sp.	16.4	3.8	7.6	7.9
Phylloceras sp.	21.2	N.A	28.8	27.5

Discussion

Sexual dimorphism and ontogeny

Some of the morphotypes described above presented sexual dimorphism characterized by differences between sizes. The presence of sexual dimorphism can be defined such as the existence of two different morphologies during the adult stage in the same species (Davis et al., 1996). This is why several of the samples have a varied size and ornamentation, which can be confused by other morphotypes, so it is necessary to take into account the micro and macro shells. The micro-shells are characterized by being evolving shells with a very marked ornamentation, while macro-shells are involute forms with less ornamentation, marked as in the micro-shell (Davis et al., 1996).

In the figures presented above, the micro conchs are displayed in the top left corner, with the exception of *Phylloceras* sp. which macro and micro conchs couldn't be identified. The Table 1 presents the average size of the most important shell parameters, as can be observed the biggest being morphotype *Phylloceras* sp. Even so, there is a parameter with missing information, this is because the samples of this morphotype were in a poor state of conservation, mostly fragmentary or with iron oxides encrusting. It is important to mention that the ammonoids described herein were selected taking into account their state of conservation, since taking accurate measures depended on that. Also, ontogeny processes can be appreciated since several of the identified samples correspond to young and adult specimens. It is important to mention that to confirm or rule out ontogenetic processes in the samples, it is necessary to know in detail the micro and macro shells of the corresponding species.

Ammonite association vs. geologic time.

Species found corresponding to the Valanginian age, particularly the occurrence of *Saynoceras verrucosum,* which according to Etayo-Serna & Gúzman-Ospitia, (2019) indicates that the segment from the Q layer to the base of the P layer is equivalent to the base of the upper Valanginian. This due to a rapid and brief global rise in sea level at the beginning of the late Valanginian that was recorded with the presence of the index fossil from the *S. verrucosum* Zone, that is, the first Upper Valanginian Zone of the Mediterranean region. Also, that the presence of these organisms was due to the influence of a river system that drained from the northwest to the southeast and interdigitated with banks of coastal ostreid mollusks, which is associated with the geological age of the Lower Cretaceous

Paleodiversity insights.

It is also important to mention the diversity of species and genera in the small sample that was drawn. These ammonites lived in an environment where they were the dominant species and taxonomic differences determined behaviors. From a sample of 116 specimens, in different states of conservation, it was determined that the species described above match with Etayo-Serna & Gúzman-Ospitia, (2019). The diversity of ammonites in the Rosa Blanca Formation, allows enriching the limited knowledge about these extinct organisms in Colombia and can support future

research projects that are guided towards the palaeoecology of the inner tropical South American Sea during the Valanginian and how similar or distinct the ammonoids faunas were in contrast to Europe, North America or southern South America during the time that the Atlantic Ocean was opening.

Conclusions

Four morphotypes were identified in the Rosa Blanca Formation layer Q-QO, being *Olcostephanus* sp., *Saynoceras verrocusum*, *Neocomites* sp. and *Phylloceras* sp.

The specimens found in the Rosa Blanca Formation, in the east of the town of Zapatoca, Santander, La Virgen West locality, in Colombia correspond to the Valanginian age. Due to their presence in the Q-QO layer.

When identifying ammonite species, it is important to take into account the differences between sexual domorphism and ontogeny to determine their taxonomy with more precision.

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Appendix.

Ammonite raw measurements (mm)

Fossil number	Shell diameter	Umbilical width	Whorl height	Whorl breadth
1	13.5	5.2	6.5	6.1
2	10.1	2.5	5.5	4.9
3	16.5	4.1	4.9	8.9
4	22.8	4.8	10.2	9.0
5	18.5	4.0	9.0	5.8
6	19.7	4.8	7.3	7.8
7	11.3	3.0	4.5	4.8
8	13.9	4.0	5.3	4.9
9	9.5	3.1	4.0	5.1
10	11.0	3.5	4.8	5.2
11	11.2	3.4	7.2	6.8
12	7.2	2.8	3.1	3.3
13	14.9	4.2	5.5	6.9

14	19.6	4.2	10.1	9.0
15	17.9	3.2	8.3	8.9
16	18.2	5.1	7.2	7.5
17	12.8	2.8	5.7	6.4
18	11.9	2.7	4.8	7.2
19	12.7	2.2	6.2	7.0
20	18.9	4.2	7.8	8.8
21	10.8	2.7	4.2	4.2
22	16.5	5.0	7.1	8.2
23	11.1	2.3	5.4	5.8
24	30.5	9.8	13.8	10.1
25	61.2	NA	29.7	23.3
26	27.5	NA	12.8	12.2
27	18.2	NA	10.1	9.4
28	18.0	NA	5.9	5.9
29	37.7	NA	13.8	10.2
30	35.3	5.5	17.2	16.3
31	18.3	3.4	7.4	6.4

32	16.5	2.2	8.2	8.6
33	8.9	2.3	6.2	5.8
34	10.4	NA	5.8	8.4
35	10.8	NA	4.9	5.5
36	12.9	NA	5.6	6.3
37	14.1	NA	6.2	8.1
38	16.6	NA	8.8	8.2
39	14.8	2.2	9.2	8.1
40	18.9	6.0	6.6	8.1
41	23.6	NA	5.2	7.0
42	25.1	4.8	13.8	12.9
43	31.2	NA	24.2	13.8
44	37.2	NA	30.2	14.5
45	35.9	NA	24.0	14.8
46	24.2	NA	27.9	15.2
47	30.8	NA	17.7	11.3
48	19.2	NA	16.3	10.5
49	42.8	NA	20.6	15.8

50	31.8	NA	25.0	12.2
51	29.8	NA	16.2	14.9
52	26.5	NA	17.5	19.2
53	16.2	NA	17.4	13.9
54	19.4	NA	12.1	7.9
55	31.2	NA	13.5	10.5
56	21.6	NA	16.3	12.7
57	29.9	NA	23.6	12.3
58	31.9	NA	22.2	14.6
59	25.6	NA	20.2	11.2
60	35.9	NA	22.8	12.5
61	19.5	NA	21.0	12.6
62	25.5	NA	17.4	9.4
63	34.0	NA	17.6	10.9
64	34.4	NA	17.6	10.1
65	30.8	NA	18.5	11.2
66	20.5	NA	19.8	12.2
67	26.2	NA	17.2	9.4

68	24.0	NA	13.2	8.9
69	20.4	NA	11.4	7.2
70	20.8	NA	16.7	8.4
71	24.6	NA	9.8	7.3
72	17.2	NA	15.6	8.5
73	24.9	4.6	14.0	8.2
74	31.1	NA	15.9	13.2
75	31.2	NA	16.5	14.4
76	17.5	NA	13.3	15.6
77	22.8	NA	15.5	12.6
78	32.5	NA	16.7	14.5
79	17.7	NA	9.1	10.1
80	12.4	NA	6.8	7.3
81	12.4	NA	7.3	7.1
82	26.7	NA	8.2	8.2
83	15.5	NA	8.5	8.5
84	14.8	NA	9.3	6.4
85	17.1	NA	8.2	6.2

86	30.0	NA	14.6	15.2
87	27.2	NA	11.8	9.1
88	29.9	NA	14.1	10.6
89	23.0	NA	11.0	8.9
90	18.4	NA	8.4	7.2
91	28.0	NA	14.2	12.1
92	22.9	NA	11.5	8.3
93	19.4	NA	9.4	9.4
94	18.8	NA	10.1	5.9
95	13.0	NA	9.4	9.8
96	36.2	NA	19.4	13.8
97	44.2	NA	19.2	14.4
98	36.6	NA	19.9	11.6
99	31.1	NA	17.7	10.0
100	30.5	NA	14.4	10.0
101	27.2	NA	17.7	13.8
102	29.4	NA	11.5	9.0
103	31.9	NA	21.8	12.0

104	32.2	NA	21.9	11.1
105	32.0	NA	16.1	8.3
106	34.0	NA	20.5	9.4
107	19.4	NA	11.0	11.0
108	25.5	NA	15.5	8.8
109	48.6	NA	32.7	23.3
110	47.0	NA	23.3	13.3
111	42.7	NA	31.3	17.7
112	32.5	NA	29.4	16.0
113	27.3	NA	12.6	14.2
114	18.0	NA	11.5	10.5
115	21.1	NA	20.5	17.2
116	41.9	NA	21.1	22.7