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Chapter 12

Barremian Deposits of Colombia: A Special Emphasis on Marine Successions

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In memory of Prof. Dr. Jost WIEDMANN (31.03.1931–02.12.1993), Prof. Dr. Wolfram BLIND (11.10.1929–02.07.2017), Dr. Hermann DUQUE CARO (22.03.1935–20.09.2015), and Dr. José Ignacio MARTÍNEZ RODRÍGUEZ (15.05.1956–17.12.2016)

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Abstract Marine Barremian deposits are represented in different lithostratigraphic units in Colombia, from the central part of the country to the north. Up to the Upper Magdalena Valley, continental deposits have been reported in the Yaví Formation; although until now, only Aptian plant remains have been recognized.

Marine deposits include the shales and biomicrites of the Trincheras Formation to the west and southwest of Bogotá; the shales and biomicrites of the Fómeque Formation to the east and northeast of Bogotá; the biomicrites, biosparites, and shales of the Upper Calcareous Member of the Tibasosa Formation to the north of Bogotá; the shales and biomicrites of the Paja Formation near Villa de Leyva and to the northwest of Bogotá in the Middle Magdalena Valley; and in some cases, the biomicrites of the "Rosablanca" Formation.

Sporadic occurrences of Barremian ammonites have been reported in the biomicrites of the Yuruma Formation, that occurs in northern Colombia near Venezuela; in the *Cretácico del* Río *Cañas* (La Guajira) deposits; and in the central and western regions of the Central Cordillera. Nevertheless, these have been poorly studied.

Other lithostratigraphic units that have been cited as being related to the Barremian deposits, albeit without biostratigraphic support, are the Tibú–Mercedes Formation and, possibly, the Río Negro Formation. Barremian ammonites have been reported in the La Naveta Formation but with controversial stratigraphic control.

Different fossil fauna and flora have been reported in these units, but ammonite biostratigraphy is the principal tool used to identify chronostratigraphic levels. Tethyan fauna allows one to correlate Barremian successions with standard biozones and biohorizons from the Mediterranean area, based on the *Psilotissotia*, *Nicklesia*, *Pulchellia*, *Gerhardtia*, *Heinzia*, etc.

The sedimentary and ecological variations in the lithological units are the consequence of environmental factors, paleoecology, and basin differentiation that have recorded tectonic or subsidence influxes due to their local paleogeographic positions.

Keywords: *Barremian deposits, biostratigraphy, lithostratigraphy, Colombia.*

Resumen Los depósitos marinos del Barremiano en Colombia están representados en diferentes unidades litoestratigráficas desde la parte central del país y hacia el norte. Para el Valle Superior del Magdalena han sido reportados depósitos continentales de la Formación Yaví, aunque allí hasta ahora se han reconocido restos vegetales del Aptiano.

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Los depósitos marinos incluyen las lodolitas y biomicritas de la Formación Trincheras al oeste y al suroeste de Bogotá; las lodolitas y biomicritas de la Formación Fómeque al este y noreste de Bogotá; las biomicritas, bioesparitas y lodolitas del Miembro Calcáreo Superior de la Formación Tibasosa al norte de Bogotá; las lodolitas y biomicritas de la Formación Paja cerca de Villa de Leyva y al noroeste de Bogotá en el Valle Medio del Magdalena; y en algunos casos las biomicritas de la Formación "Rosablanca".

Para las biomicritas de la Formación Yuruma que se presentan al norte de Colombia, cerca de Venezuela; los depósitos del *Cretácico del Río Cañas* (La Guajira); y las regiones central y occidental de la cordillera Central se han reportado ocurrencias esporádicas de amonitas del Barremiano. Sin embargo, estas han sido muy poco estudiadas.

La Formación Tibú–Mercedes y posiblemente la Formación Río Negro son otras unidades litoestratigráficas que han sido relacionadas con los depósitos del Barremiano, aunque sin soporte bioestratigráfico. En la Formación La Naveta se reportaron amonitas del Barremiano, pero con control estratigráfico insuficiente.

Diferentes fósiles de fauna y flora han sido mencionados dentro de las unidades referidas, pero la bioestratigrafía de las amonitas es la principal herramienta para identificar los niveles cronoestratigráficos. La fauna del Tetis permite correlacionar las sucesiones del Barremiano con las biozonas y biohorizontes estándar del área del Mediterráneo con base en *Psilotissotia*, *Nicklesia*, *Pulchellia*, *Gerhardtia*, *Heinzia*, etc.

Las variaciones sedimentarias y ecológicas de las unidades litológicas son consecuencia de factores ambientales, la paleoecología y la diferenciación de la cuenca que puede tener influencia tectónica o de subsidencia debido a la posición paleogeográfica local.
Palabras clave: *depósitos del Barremiano, bioestratigrafía, litoestratigrafía, Colombia.*

1. Introduction

Barremian marine deposits in Colombia outcrop in different locations; they principally outcrop along the Eastern Cordillera, although some occur in the Central Cordillera, and others occur in northern Colombia (La Guajira province). It may be possible to find other deposits, such as those in the continental successions to the north of the Upper Magdalena Valley and the serranía del Perijá (Figure 1), but there are not enough data to indicate that they comprise a Barremian range.

Von Buch (1838, 1839) first showed the existence of Lower Cretaceous deposits in Colombia based on the paleontological collection of von Humboldt and Degenhardt, which is kept in the Museum of Natural History in Berlin (Germany). Thus, the first allusion to the Villeta denomination (von Humboldt, 1816, 66; 1823; 1853; 1888) was Villeta shales (Thonschiefer). Thereafter, Uhlig (1882, 94–95) provided the first mention of Barremian deposits in Colombia.

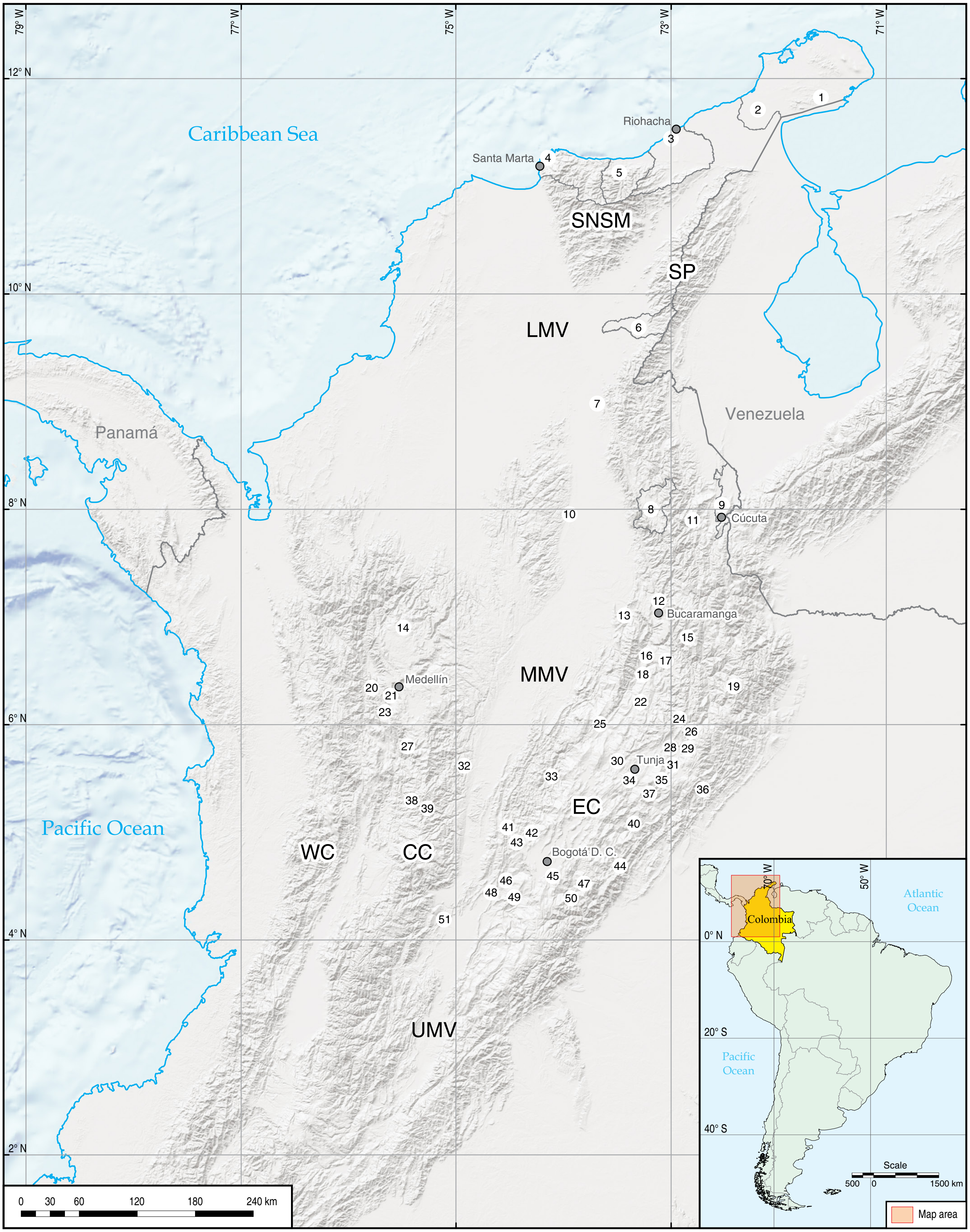
The most investigated succession in Colombia is represented near Villa de Leyva (Boyacá) in the Paja Formation (cf. Bürgl, 1954, 1956; Etayo–Serna, 1968a, 1968b, 1968c; Patarroyo, 2000a, 2000b, 2000c, 2004), which is used here as a reference to other marine lithostratigraphic units that include Barremian deposits. Ammonites, wood, bivalves, gastropods, echinoids, serpulids, foraminifera, and vertebrates have been recognized in the Barremian successions.

The Barremian ammonites from Colombia record a Tethyan influence, but not all genera and species from the western Mediterranean province are present in Colombian deposits (Patarroyo, 2000a, 2000b, 2004).

The Barremian boundary with the upper Hauterivian in Colombia remains unclear. *Crioceratites* can be found in upper Hauterivian and lower Barremian deposits. In the upper part of the upper Barremian, *Colchidites* and then *Pseudocrioceras* (Kakabadze & Sharikadze, 2004) appear, whereas in the lower Aptian, *Procheloniceras* (Kakabadze & Sharikadze, 2004),

→

Figure 1. Location map with the main places mentioned, as follows: (1) Yuruma Hill, (2) Uribia, (3) Riohacha, (4) Santa Marta, (5) Mingueo (Dibulla), (6) Becerril, (7) Pailitas, (8) Ábrego, (9) Cúcuta, (10) Simití, (11) Gramalote, (12) Bucaramanga, (13) Betulia, (14) Yarumal, (15) San Andrés (Santander), (16) Barichara, (17) Curití, (18) Socorro, (19) El Cocuy, (20) Ebéjico, (21) Medellín, (22) Oiba, (23) La Estrella, (24) Belén, (25) Vélez, (26) Betéitiva, (27) Abejorral, (28) Tibasosa, (29) Corrales, (30) Villa de Leyva, (31) Firavitoba, (32) Berlín, (33) Muzo, (34) Tunja, (35) Pesca, (36) Pajarito, (37) Rondón, (38) San Félix, (39) Valle Alto, (40) Garagoa, (41) Villeta, (42) La Vega, (43) Sasaima, (44) Gachalá, (45) Bogotá, (46) Apulo, (47) Fómeque, (48) Tocaima, (49) Viotá, (50) Cáqueza, and (51) El Cobre Creek (San Luis, Tolima). (LMV) Lower Magdalena Valley; (MMV) Middle Magdalena Valley; (UMV) Upper Magdalena Valley; (SNSM) Sierra Nevada de Santa Marta; (SP) Serranía del Perijá; (EC) Eastern Cordillera; (CC) Central Cordillera; (WC) Western Cordillera.


79° W
77° W
75° W
73° W
71° W
12° N
10° N
8° N
6° N
4° N
2° N
Caribbean Sea
Pacific Ocean
Panamá
Venezuela
Riohacha
Santa Marta
Cúcuta
Bucaramanga
Medellín
Tunja
Bogotá D. C.
SNSM
SP
LMV
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46
47
48
49
50
51
0
30
60
120
180
240 km
70° W
50° W
0° N
20° S
40° S
Atlantic Ocean
Pacific Ocean
Colombia
Scale
500
0
1500 km
Map area

Dufrenoyia, and *Cheloniceras* appear. Between these intervals, the fossil record is poor. Unfortunately, Bürgl (1956) introduced three–fold divisions of the Barremian in Colombia (lower, middle, and upper); therefore, international researchers believe that this is among the best places to recognize these marine deposits. Although Mutterlose et al. (2014, 260) officially used the mid–Barremian as the boundary interval between the upper lower–lower upper Barremian and the lower/upper Barremian, the International Commission on Stratigraphy only recognizes the lower and upper Barremian.

2. Barremian Stage

Coquand (1861) originally introduced the Barremian denomination near Barrême (Alpes–de–Haute–Provence, SE France), which is the type locality. Busnardo (1965) clarified the definition of the Barremian Stage using the outcrops along the way to Angles (SE France) because, according to Coquand, it actually included the upper Hauterivian and Barremian succession.

Although the Global Boundary Stratotype Section and Point (GSSP) of the Barremian Stage has not been established until now, its ammonite biostratigraphy has been used to recognize its subdivisions in the lower and upper Barremian following the western Mediterranean successions (Figure 2). The lower Barremian substage includes 5 biozones (Reboulet et al., 2014, 2018), some subzones and biohorizons (Reboulet et al., 2014, Table 1); the upper Barremian substage includes 4 biozones (Reboulet et al., 2014, 2018), more subzones and one biohorizon (Reboulet et al., 2014, Table 1). A candidate for the GSSP (Company et al., 1995; Ogg et al., 2012; Rawson et al., 1996) is a succession in Río Argos (near Caravaca, Murcia province, Spain) with the first apparition data (FAD) of the *Taveraidiscus hugii* auctorum formerly termed "*Spitidiscus*" *hugii* (Company et al., 1995; Hoedemaeker et al., 1993, 2003) and the *Avramidiscus vandeckii* ammonite group (cf. Company et al., 1995; Rawson et al., 1996). The boundary interval in Italy falls within the uppermost part of magnetic polarity zone M4n (at approximately Chron M4n.8 ¼ "M5n.8") (Bartolocci et al., 1992; Channell et al., 1995; as cited in Ogg et al., 2012).

The boundary between the lower and upper Barremian is related to the FAD of the ammonite "*Ancyloceras*" *vendenheckii* (Rawson et al., 1996, 28; Reboulet et al., 2009, 2011, 2014, 2018; Ogg et al., 2012). A GSSP substage is proposed near Caravaca, Spain (Ogg et al., 2012; Company et al., 1995). This substage boundary level is within the uppermost part of the magnetic polarity zone M3r (at approximately Chron M3r.8) in Italy (Bartolocci et al., 1992; Channell et al., 1995; as cited in Ogg et al., 2012).

2.1. Biostratigraphy

"Biostratigraphic units (biozones) are bodies of strata that are defined or characterized on the basis of their contained fossils. Biostratigraphic units only exist where the particular diagnostic feature or attribute on which they are based has been identified. Biostratigraphic units, therefore, are objective units based on the identification of fossil taxa" (Murphy & Salvador, 1999, 261).

This means that taxonomy affects the denominations of biozones; however, taxonomy may be artificial because generic determination principally depends on the interpretation of the specialist. Therefore, some citations here related to biostratigraphy and taxonomy do not follow some postulates that have recently been recognized (Reboulet et al., 2011, 2014, 2018), such as some species of "*Heinzia*" and "*Gerhardtia*". In taxonomic hierarchy, only the species is tangible; the other categories are artificial and are dependent on the author (cf. Vermeulen & Klein, 2006). Therefore, the specific determination, which is independent of the generic designation, allows one to identify stratigraphic levels that can be correlated. Therefore, it may be considered that only one or two authors have established synonym lists of Barremian ammonites (cf. Vermeulen & Klein, 2006).

In this study, some Barremian generic denominations follow those of classical publications, such as *Psilotissotia* sensu Hyatt (1900), *Gerhardtia* and *Carstenia* sensu Hyatt (1903), and *Heinzia* sensu Bürgl (1956).

The Barremian Stage in the western Mediterranean province (Reboulet et al., 2014, Table 1; 2018, Table 1b) is officially divided into the lower and upper Barremian. To Reboulet et al., (2014, Table 1), the lower Barremian includes 5 biozones, some subzones and biohorizons (Figure 2), including *Taveraidiscus hugii* auctorum (*T. hugii* auctorum and *Psilotissotia colombiana* Subzones), *Kotetishvilia nicklesi*, *Nicklesia pulchella*, *Kotetishvilia compressissima* (*Holcodiscus fallax*, *Nicklesia didayana*, "*Heinzia*" *communis*, and *Subtorcapella defayae* Horizons), and *Moutoniceras moutonianum* (*Coronites darsi* and "*Heinzia*" *caicedi* Horizons). The upper Barremian includes 4 biozones, some subzones and horizons (Figure 2), such as *Toxancyloceras vandenheckii* (*T. vandenheckii* and *Barrancyloceras barremense* Subzones), *Gerhardtia sartousiana* (*G. sartousiana*, "*G.*" *provincialis*, and *Hemihoplites feraudianus* Subzones), *Imerites giraudi* (*I. giraudi* and *Heteroceras emerici* Subzones), and *Martelites sarasini* (*M. sarasini* (*Anglesites puzosianum* Horizon) and *Pseudocrioceras waagenoides* Subzones). Recently, Reboulet et al. (2018) introduced new considerations related to ammonite taxonomy and biostratigraphy of the Barremian (Figure 2), in which they did not use biohorizons. Moreover, they referred that the meeting in Vienna of 2017 deleted the term "auctorum" from the *Taveraidiscus hugii* index species (cf. Figure 2) and stated the problematic identification of *Psilotissotia colombiana* in the Mediterranean forms.

In Colombia, most Barremian ammonites record a Tethyan influence that allows one to correlate these deposits with the western Mediterranean successions. *Psilotissotia malladae*, *Nicklesia pulchella*, *Pulchellia communis*, "*P*". *caicedi*, *Heinzia provincialis,* and *Carstenia lindigii* are present in both areas.

West Mediterranean standard zonation

Barremian	Reboulet et al. (2014) Zones	Reboulet et al. (2014) Subzones	Reboulet et al. (2014) Horizons	Reboulet et al. (2018) Zones	Reboulet et al. (2018) Subzones
upper	*Martelites sarasini*	*Pseudocrioceras waagenoides*		*Martelites sarasini*	*Pseudocrioceras waagenoides*
		M. sarasini	*Anglesites puzosianum*		*M. sarasini*
	Imerites giraudi	*Heteroceras emerici*		*Imerites giraudi*	*Heteroceras emerici*
		I. giraudi			*I. giraudi*
	Gerhardtia sartousiana	*Hemihoplites feraudianus*		*Gerhardtia sartousiana*	*Hemihoplites feraudianus*
		"*Gerhardtia*" *provincialis*			"*Gerhardtia*" *provincialis*
		G. sartousiana			*G. sartousiana*
	Toxancyloceras vandenheckii	*Barrancyloceras barremense*		*Toxancyloceras vandenheckii*	*Gassendiceras alpinun*
		T. vandenheckii			*T. vandenheckii*
lower	*Moutoniceras moutonianum*		"*Heinzia*" *caicedi*	*Moutoniceras moutonianum*	
			Coronites darsi		
	Kotetishvilia compressissima		*Subtorcapella defayae*	*Kotetishvilia compressissima*	*Holcodiscus caillaudianus*
			"*Heinzia*" *communis*		
			Nicklesia didayana		*Holcodiscus fallax*
			Holcodiscus fallax		
	Nicklesia pulchella			*Nicklesia pulchella*	
	Kotetishvilia nicklesi			*Kotetishvilia nicklesi*	
	Taveraidiscus hugii auctorum	*Psilotissotia colombiana*		*Taveraidiscus hugii*	*Psilotissotia colombiana*
		T. hugii auctorum			*T. hugii*

Figure 2. Western Mediterranean standard zonation of the Barremian Stage (Taken from Reboulet et al., 2014, 2018).

Following the best exposed Barremian deposits in Colombia, as a part of the Paja Formation (Hauterivian – Aptian) in the Villa de Leyva area (Figures 3, 4, 5), it is possible to affirm that the faunal representation is better in the lower Barremian deposits than in those of the upper Barremian deposits. Ammonites from the lower Barremian are represented by *Psilotissotia colombiana* (d'Orbigny, 1842); *P. malladae* (Nicklès, 1894); *Pedioceras caquesense*; *Crioceratites* sp., *C.* (*Paracrioceras*) *leyvaensis* Kakabadze & Hoedemaeker, 2004; *Buergliceras buerglii* Etayo–Serna, 1968c; *Acanthoptychoceras* ? *trumpyi* Kakabadze & Thieuloy, 1991 (cf. Klein et al., 2007); *Nicklesia pulchella* (d'Orbigny, 1840); *N. nodosa* Bürgl, 1956; *N. karsteni* Hyatt; 1903; *Parasaynoceras horridum* (d'Orbigny, 1840); *Acrioceras julivertii* Etayo–Serna, 1968c; *Valdedorsella inca* (Forbes, 1845); *Karsteniceras beyrichi* (Karsten, 1858); *Phylloceras* sp.; *Lytoceras* sp.; *Pulchellia galeata* (von Buch, 1838); *P. communis* Bürgl, 1956; *P. hettneri* Gerhardt, 1897; *P. fasciata* Gerhardt, 1897; *P. selecta* Gerhardt, 1897; and "*P*". *caicedi* (Karsten, 1858). Ammonites from the upper Barremian are represented by *Gerhardtia veleziensis* (Hyatt, 1903); *G. galeatoides* (Karsten, 1858); *Heinzia provincialis* (d'Orbigny, 1850); *H. colleti* (Bürgl, 1956); *Carstenia lindigii* (Karsten, 1858); *Colchidites breistrofferi* Kakabadze & Thieuloy, 1991; *Pseudohaploceras* cf. *liptoviense* (Zeuschner 1856); *Pseudocrioceras anthulai* (Eristavi, 1955); *Ancyloceras* sp., *Heteroceras* sp., *Kutatissites* sp., and *Moutoniceras* cf. *moutonianum* (d'Orbigny, 1850).

Until now, it has not been clear if *Spitidiscus* (*S. ursulae* (Riedel, 1938), *S. simitiensis* (Haas, 1960)), *Toxancyloceras,* and *Imerites* are present in the Barremian deposits.

Patarroyo (2000a, 2000b, 2004) introduced interval zones to the Colombian Barremian deposits (Figure 6) following the first appearance data of lower Barremian taxa, such as *Psilotissotia colombiana*, *Nicklesia pulchella*, and *Pulchellia galeata*, and upper Barremian taxa, such as *Heinzia* (*Gerhardtia*) *veleziensis* (actually *Gerhardtia veleziensis,* Figure 7) and *Colchidites breistrofferi*. However, some intervals in this succession include poor fossil recovery or there are no fossils at all. Thus, the upper part of the zones can be considered intrazones with respect to *Pulchellia galeata*, *Gerhardtia veleziensis,* and *Colchidites breistrofferi* (Figure 6). However, directly above the *Colchidites breistrofferi* Zone, Kakabadze & Sharikadze (2004) suggested three biostratigraphical levels, the first is the succession with *Pseudocrioceras anthulai* (uppermost Barremian), the second with *Procheloniceras albrechtiaustriae* (lowest Aptian), and the third with *Cheloniceras kiliani* (Figure 7), that are below the first Aptian assemblage zone of Etayo–Serna (1979). But directly above *Colchidites breistrofferi* Zone there are no sufficient outcrops (containing rich ammonites fauna) and therefore to solve the problem of determination of the uppermost Barremian *Pseudocrioceras anthulai* Horizon still needs further additional palaeontological and lithological data (cf. Kakabadze & Sharikadze, 2004).

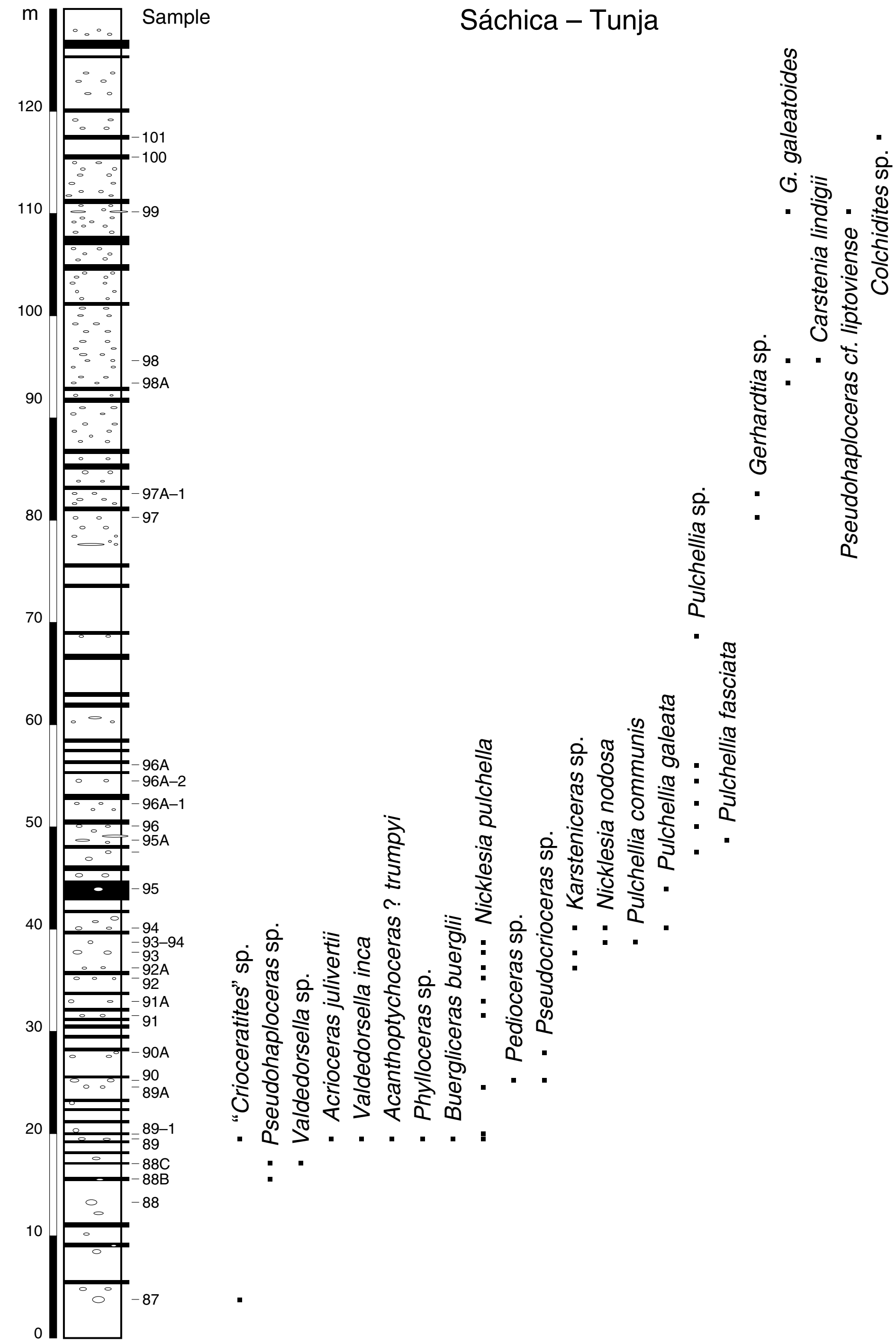

Figure 3. Succession of the Sáchica–Tunja way with the Barremian ammonite distribution of the Paja Formation (Boyacá province).

2.2. Lithostratigraphy

Although the Cretaceous successions along the Eastern Cordillera in Colombia have been studied in different investigations, they are poorly understood. Homonymies, synonymies, and stratigraphic generalization are the most important problems related to the differentiation of the basin.

In central Colombia, Barremian deposits are included in the Paja Formation (cf. Basse, 1928; Bürgl, 1954, 1956; Collet, 1924; Etayo–Serna, 1964, 1968a, 1968b, 1968c; Gerhardt, 1897; Haas, 1960; Karsten, 1858; Patarroyo, 1997, 2000a, 2000b, 2000c, 2004), the Trincheras Formation (cf. Basse, 1950; Cáceres & Etayo–Serna, 1969a, 1969b; Patarroyo, 2011; von Buch, 1838, 1839), the Fómeque Formation (cf. Bürgl, 1956;

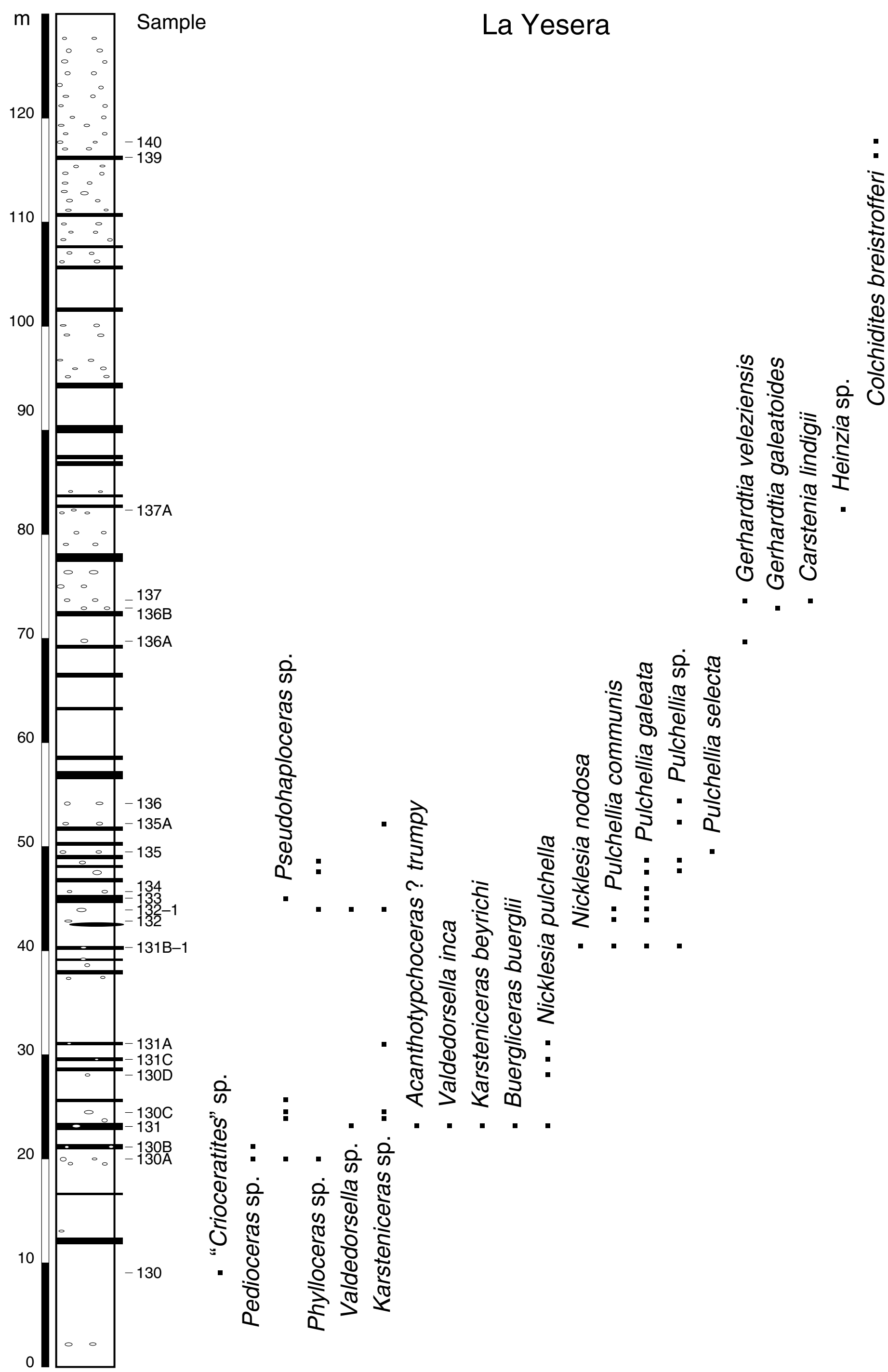

Figure 4. Succession of La Yesera Hill with the Barremian ammonite distribution of the Paja Formation in Villa de Leyva (Boyacá province).

Etayo–Serna, 1964; Karsten, 1858; Royo y Gómez, 1945a; Ramos–Gámez, 2016; Ulloa et al., 2000), the Upper Calcareous Member of the Tibasosa Formation (Patarroyo, 2005, 2017), in some areas of the Central Cordillera in the Quebradagrande Complex (cf. Etayo–Serna, 1985a; Grosse, 1926), and occasionally in the "Rosablanca" Formation (Blau, 1993; Gaona–Narváez et al., 2013; Etayo–Serna in Mantilla–Figueroa et al., 2006; Morales et al., 1958; Patarroyo, 2017). They have also been found in northern Colombia in La Guajira province, in the poorly known successions of the *Cretácico del Río Cañas* (Colmenares et al., 2007) and the Yuruma Formation (Bürgl, 1958; Patarroyo, 2011; Renz, 1960; Rollins, 1965). Following Fabre (1985) and Etayo–Serna (1985b), the "Areniscas de Las Juntas" Formation comprises Barremian deposits, and in the serranía del

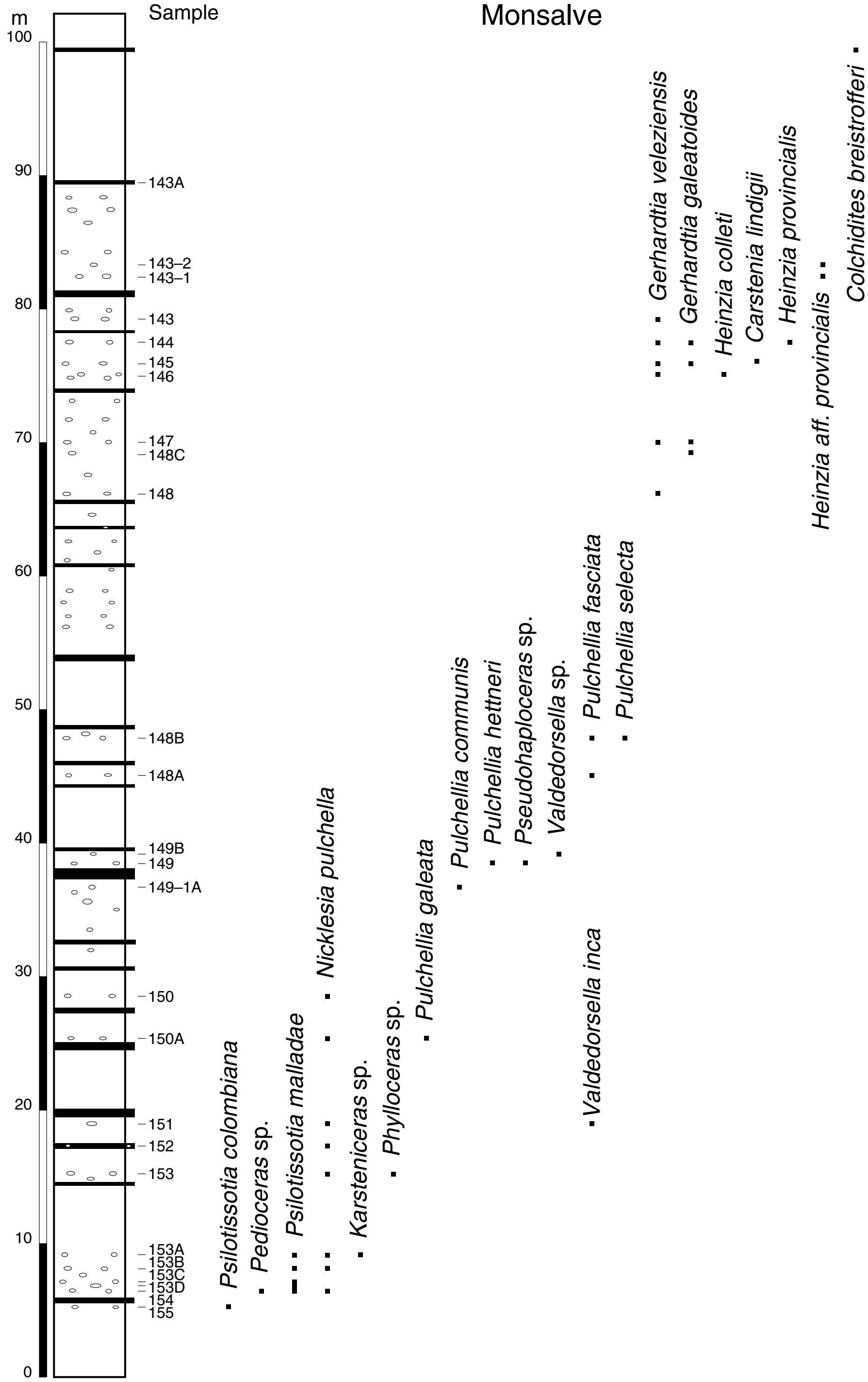

Figure 5. Succession of the Monsalve Hill with the Barremian ammonite distribution of the Paja Formation in Villa de Leyva (Boyacá province).

Perijá and Catatumbo areas, the Río Negro Formation contains sandy Barremian deposits (Julivert, 1968, 415–417; Petrash et al., 2016, Figure 2; Renz, 1959, 6; Sutton, 1946; van Andel, 1958), given the existence of Aptian ammonites in the overlying Cogollo Formation or Group in Venezuela and, probably, in some places in Colombia. Barremian ammonites have been reported between Ábrego and Gramalote near Cúcuta (Norte de Santander) (Royo y Gómez in Botero–Restrepo & Sarmiento–Rojas, 1947, 36; Bürgl, 1956, 32) are now considered to be part of the Tibú and Mercedes Formations (Vargas & Arias, 1981). Some citations without illustrations related to Barremian fauna are found in Petters (1954) in Becerril and Pailitas (Cesar province), in Langston & Durham (1955) and in Etayo–Serna et al. (1969, 232). Other citations have mentioned Barremian

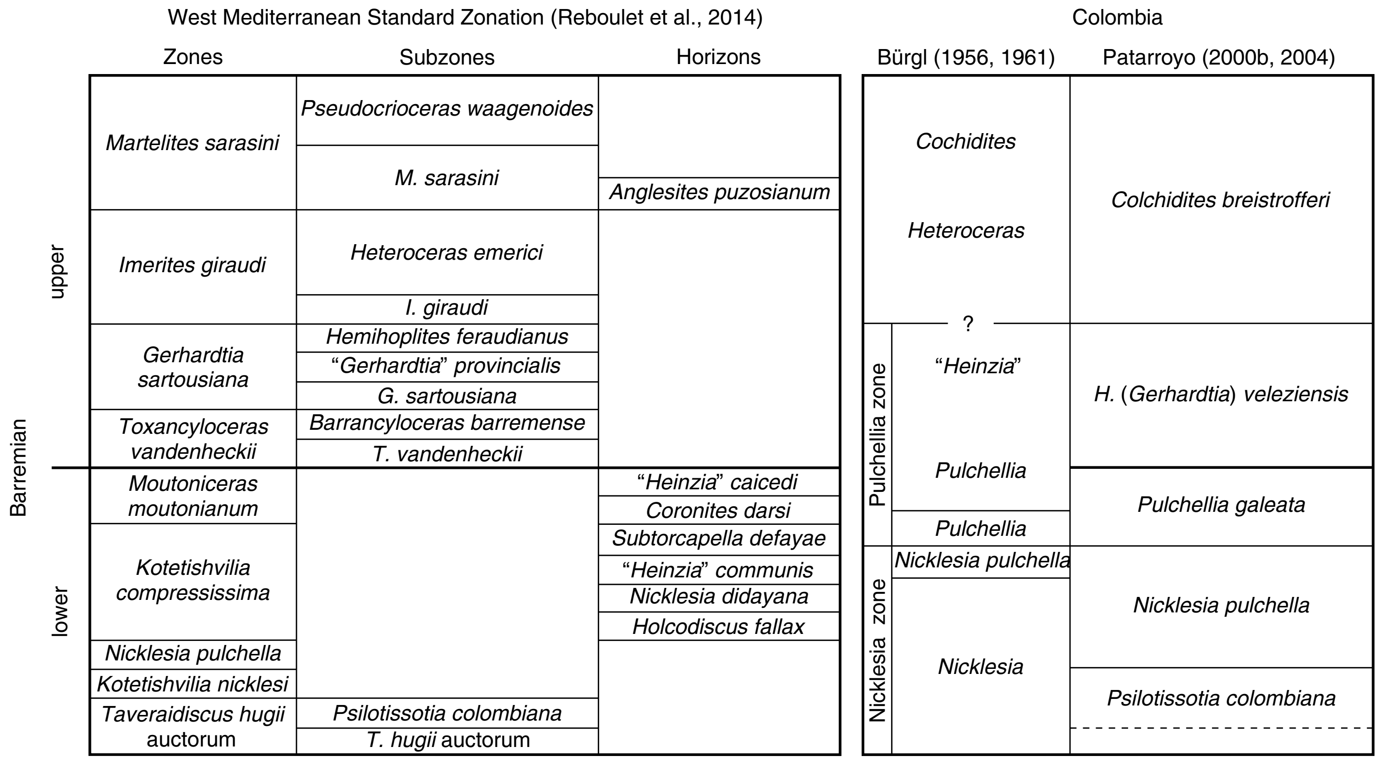

Figure 6. Western Mediterranean standard zonation of the Barremian Stage (Taken from Reboulet et al., 2014) and biostratigraphy correlated to the Colombian Barremian.

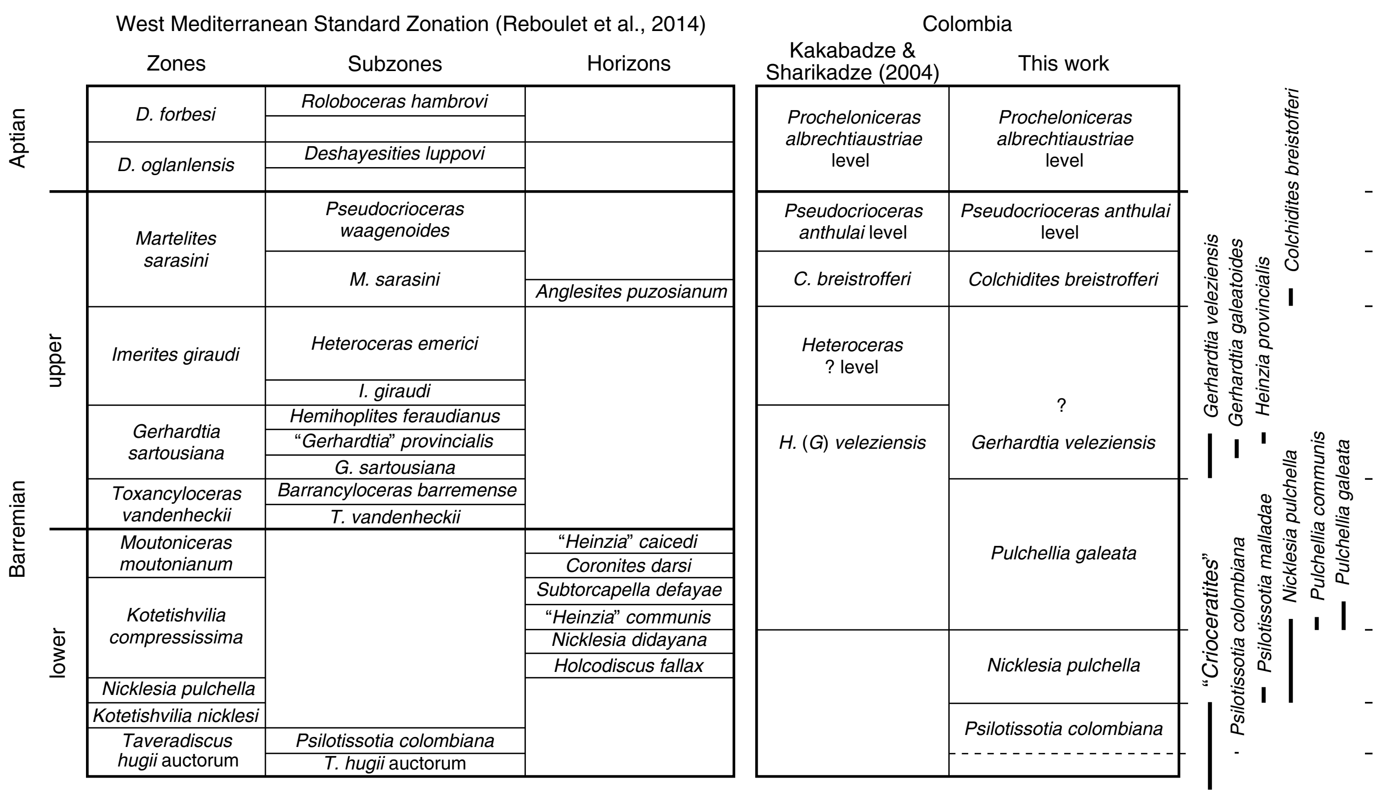

Figure 7. Western Mediterranean standard zonation of the Barremian Stage (Taken from Reboulet et al., 2014) and the new correlations of the biostratigraphy to the Colombian Barremian.

deposits in El Cobre Creek from San Luis (Tolima province), in San Andres (Santander province) by Acosta (1960, 36) and in central Colombia in the denominated Muzo Formation and El Peñón Formation (Reyes et al., 2006). The continental deposits extending from the Yaví Formation to the northern Upper Magdalena Valley and the Río Negro Formation of the serranía del Perijá likely represent Barremian successions.

2.2.1. Paja Formation

The Paja Formation was informally introduced by Wheeler (1929, 5) as the "La Paja" Formation; however, since Morales et al. (1958, 648), it has been better known by its formal name as the Paja Formation. Because this denomination has been more widely diffused, it is not convenient to readopt the old denomination following the priority recommendation of the International Commission on Stratigraphy: "Publication of a properly proposed, named, and described unit has priority. However, priority alone does not justify displacing a well–established name by one not well known or rarely used; nor should an inadequately established name be preserved merely because of priority" (Murphy & Salvador, 1999, 258). There is not a type section designation or description for the Paja Formation; therefore, a lectostratotype is necessary to typify this lithostratigraphic unit, although its name originates from La Paja Creek (in the Middle Magdalena Valley to the NW of Bogotá), which is a stream that principally follows the bed direction (Figure 8). Shales, biomicrites, and calcareous concretions represent the succession, which is 625 m in thickness at the type locality (Morales et al., 1958, 650). Barremian and Aptian fossils are included in the Paja Formation at the type locality (Tablazo area, Santander province). *Nicklesia pulchella*, *Psilotissotia* sp., *Valdedorsella cf. inca*, *Pulchellia galeata*, *Karsteniceras* sp., and *Gerhardtia veleziensis* have been recovered near Barichara (Santander province) in the Barremian deposits of the Paja Formation (Figures 9, 10, 11). The lower boundary with the Rosablanca Formation is sharp (Valanginian – Hauterivian, cf. Etayo–Serna in Guzmán, 1985; Schemm–Gregory et al., 2012), although near Barichara (Santander province), the lowest Barremian ammonites, including *Valdedorsella* or *Pseudohaploceras* sp. and *Pedioceras* sp. (Figure 12), were found towards the top of the Rosablanca Formation. The upper boundary of the Paja Formation is transitional to the Tablazo Formation (Aptian – Albian). However, in the Villa de Leyva area (Boyacá province), the Paja Formation (Figure 13) includes deposits ranging from the Hauterivian to the Aptian (Etayo–Serna, 1968a, 1968b, 1968c; Patarroyo, 2000a, 2000b, 2004); as in the Vélez area (Patarroyo, 2009), they overlie the Ritoque Formation (Valanginian – Hauterivian) and underlie the "San Gil inferior" Formation (Aptian – Albian). *"Crioceratites"* sp., *Paracrioceras leyvaense*, *Psilotissotia colombiana*, *P. malladae*, *Buergliceras buerglii*, *Acanthoptychoceras*? *trumpyi*, *Pedioceras*

Figure 8. La Paja Creek valley (Betulia, Santander province near Puente El Tablazo). South margin of the Sogamoso River or Dam.

caquesense, *Nicklesia pulchella*, *N. nodosa*, *Lamellapthycus* ? sp., *Valdedorsella inca*; *Karsteniceras beyrichi*, *Phylloceras* sp.; *Pseudohaploceras* sp., *Pulchellia galeata*, *P. communis*, *P. hettneri*, *P. fasciata*, *P. selecta*, *Gerhardtia veleziensis, G. galeatoides*, *Heinzia provincialis*, *H. colleti, Carstenia lindigii*, and *Colchidites breistrofferi* (Figures 12, 14, 15, 16, 17) have been found in the Barremian deposits of the Paja Formation (Figures 3, 4, 5) in the Villa de Leyva area (Boyacá province). Moreover, in the Vélez area (Santander province), "*Pulchellia*" *caicedi* and *Lytoceras* sp. (Figures 18, 19) have also been found (Bustos, 2017). To the Middle Magdalena Valley (Tablazo–Magdalena Sub–basin) area, exceptional Barremian deposits are recognized in the "Rosablanca" Formation (Blau, 1993; Gaona–Narváez et al., 2013; Patarroyo, 2017) because of the presence of *Gerhardtia veleziensis*, *G. galeata*, *Kutatissites* sp., and *Ancyloceras*? sp. (Figure 20) and in the eastern Central Cordillera (Etayo–Serna in Mantilla–Figueroa et al., 2006; Morales et al., 1958) near Simití (south Bolivar province).

2.2.2. Fómeque Formation

The Fómeque Formation (Hubach, 1931) to the east and northeast of Bogotá contains shales, sandstones, biomicrites, biosparites, and calcareous concretions that range from the upper Hauterivian to the Aptian (Bürgl, 1959; Ramos–Gámez, 2016; Royo y Gómez, 1945b, 116). Unfortunately, this lithostratigraphic unit does not have a type section; therefore, its description is very poor. However, it clearly contains Barremian fossils (Breistroffer, 1936; Bürgl, 1956; Campbell & Bürgl, 1965; Haas, 1960; Hubach, 1957a, 1957b; Karsten, 1858; Ramos–Gámez, 2016; Royo y Gómez, 1945b). *Nicklesia pulchella*, *Gerhardtia* cf. *galeatoides,* and *Atherfieldastacus*? sp. (Figures 12, 21) have been recovered in the Barremian deposits of the Fómeque Formation (Ramos–Gámez, 2016).

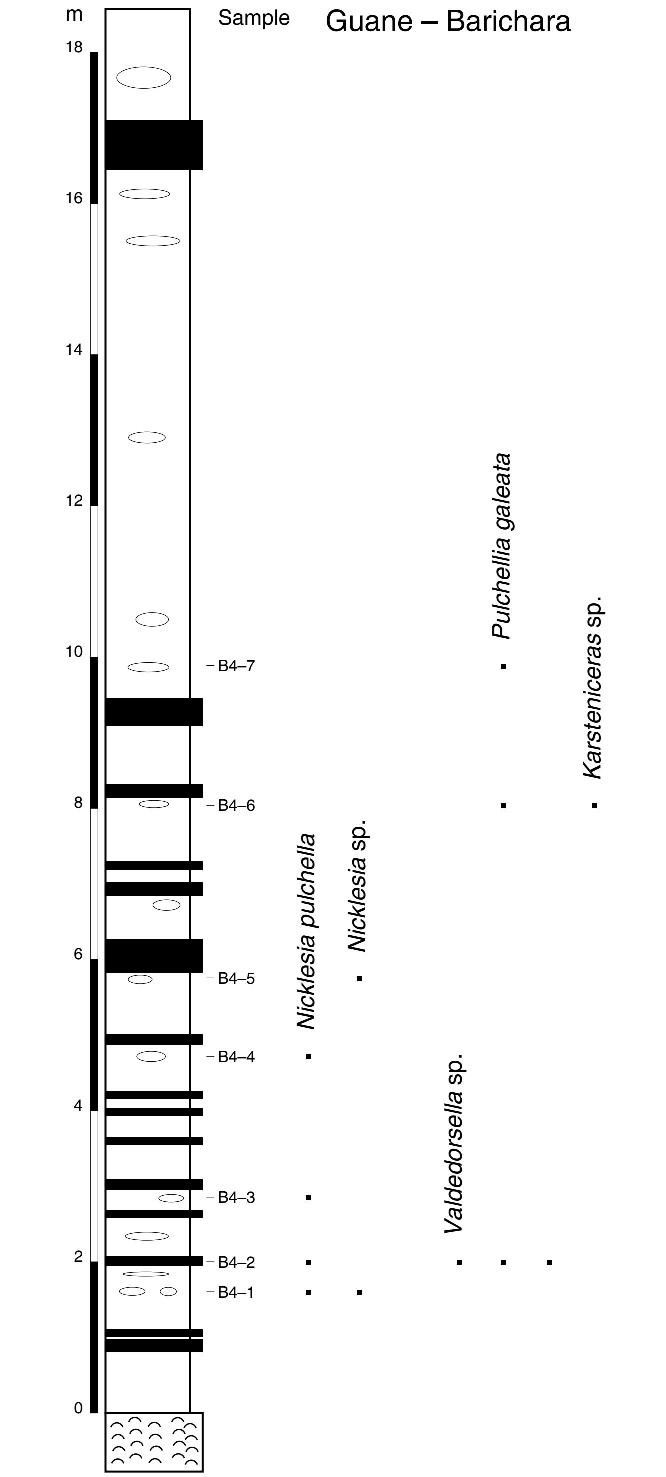

Figure 9. Lower Barremian succession of the Barichara–Guane with the ammonite distribution of the Paja Formation (Santander province).

2.2.3. Trincheras Formation

The Trincheras Formation (Cáceres & Etayo–Serna, 1969a) contains shales, biomicrites, and calcareous concretions that range from the upper Hauterivian to the Aptian (Patarroyo, 2013). Unfortunately, this lithostratigraphic unit does not have a type section description; therefore, its reconnaissance is very poor, but it clearly contains Barremian fossils (Bürgl, 1956; Collet, 1924; Cáceres & Etayo–Serna, 1969a, 1969b; Gerhardt, 1897; Patarroyo, 2013; Riedel, 1938; Royo y Gómez, 1945a; von Buch, 1838, 1839). The deposits of the underlying La Naveta Formation are considered to be Barremian (Bürgl, 1955; Cáceres & Etayo–Serna, 1969a, 1969b; Olsson, 1956; Petters, 1954) however, deposits in its upper part may be considered Hauterivian (cf. Patarroyo, 2013) because the lower deposits of the overlying Trincheras Formation represent Hauterivian deposits (cf. Etayo–Serna in Moreno, 1993; Patarroyo, 2013). *Nicklesia pulchella* and *Pulchellia galeata* (Figure 21) have been found in the Barremian deposits of the middle part of the Trincheras Formation (Patarroyo, 2013).

2.2.4. Upper Calcareous Member (Calcáreo Superior Member of the Tibasosa Formation)

The Tibasosa Formation (Renzoni & Ospina, 1969) includes a succession with four members that likely ranges from the Berriasian to the Aptian and clearly includes Valanginian, Hauterivian, Barremian, and Aptian ammonites (Patarroyo, 2002, 2003, 2005, 2017; Patarroyo & Salamanca–Saavedra, 2013). The type section is along Guadube Creek (known as Manecuche) in Tibasosa (Boyacá province). Its Upper Calcareous Member ranges from the Barremian to the Aptian (Patarroyo, 2005, 2017), and is principally represented by biomicrites, biosparites, poor sandstones, shales, and calcareous concretions towards the upper part.

Nicklesia pulchella, *Pedioceras caquesense*, *Pulchellia galeata*, *P. fasciata*, and *"Crioceratites"* sp. (Figure 22) have been recovered in Barremian deposits of the Upper Calcareous Member of the Tibasosa Formation.

2.2.5. Yuruma Formation

The Yuruma Formation, which was proposed by geologists from the Richmond Exploration Company (1947 in Rollins, 1965, 25), was formalized by Renz (1956 in Julivert, 1968) as a calcareous succession that included two parts: the lower and upper Yuruma. Renz (1960) restricted the Yuruma Formation to the upper Yuruma and redefined the lower Yuruma deposits of Renz (1956 in Julivert, 1968) as the Moina Formation. The Yuruma denomination originates from Yuruma Hill (Figure 23) in the high Guajira (La Guajira province); its type section is west of this hill (Renz, 1960, 331), and it includes Barremian deposits. The Yuruma Formation comprises marls, shales, and marly limestones with oysters, other bivalves, equinoids, and ammonites (Rollins, 1965, 26).

Nicklesia, *Pulchellia*, *Pedioceras*, *Gerhardtia* and *Heinzia* have been reported but without illustrations; therefore, their stratigraphic position is poor understood.

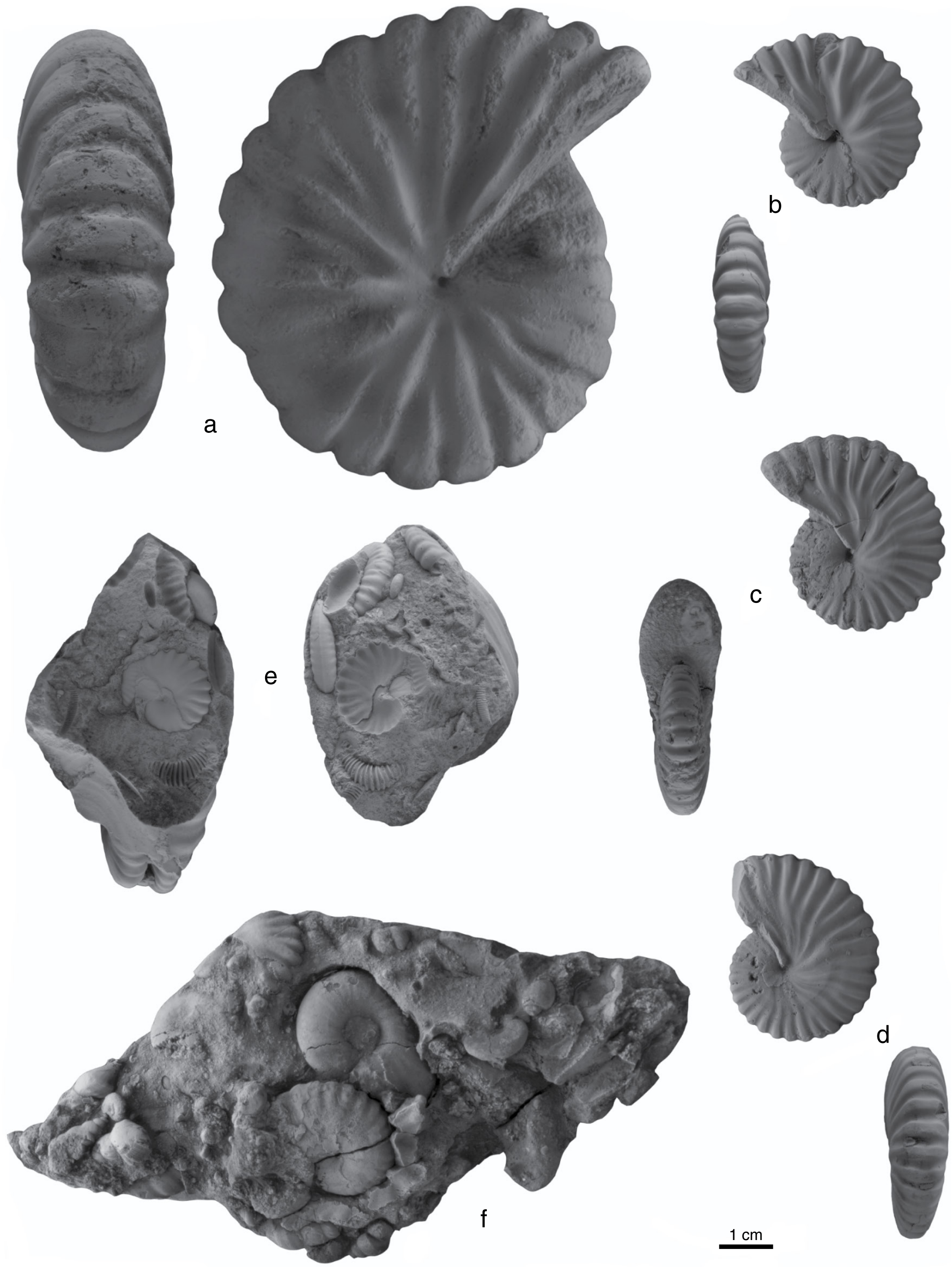

Figure 10. (a) *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Guane by Barichara (Santander province). Sample G5–6–1. **(b)** *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Guane by Barichara (Santander province). Sample G4–6. **(c)** *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Guane by Barichara (Santander province). Sample G4–3. **(d)** *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Guane by Barichara (Santander province). Sample G4–2. **(e)** Fragment of body chamber ammonite with *Nicklesia pulchella* (d'Orbigny), *Psilotissotia* sp., *Karsteniceras* sp., and gastropods. Lower Barremian. Guane by Barichara (Santander province). Sample Pt–2. **(f)** *Nicklesia pulchella* (d'Orbigny), *Pseudohaploceras*? sp., and gastropods. Lower Barremian. Guane by Barichara (Santander province). Sample B4–2–2.

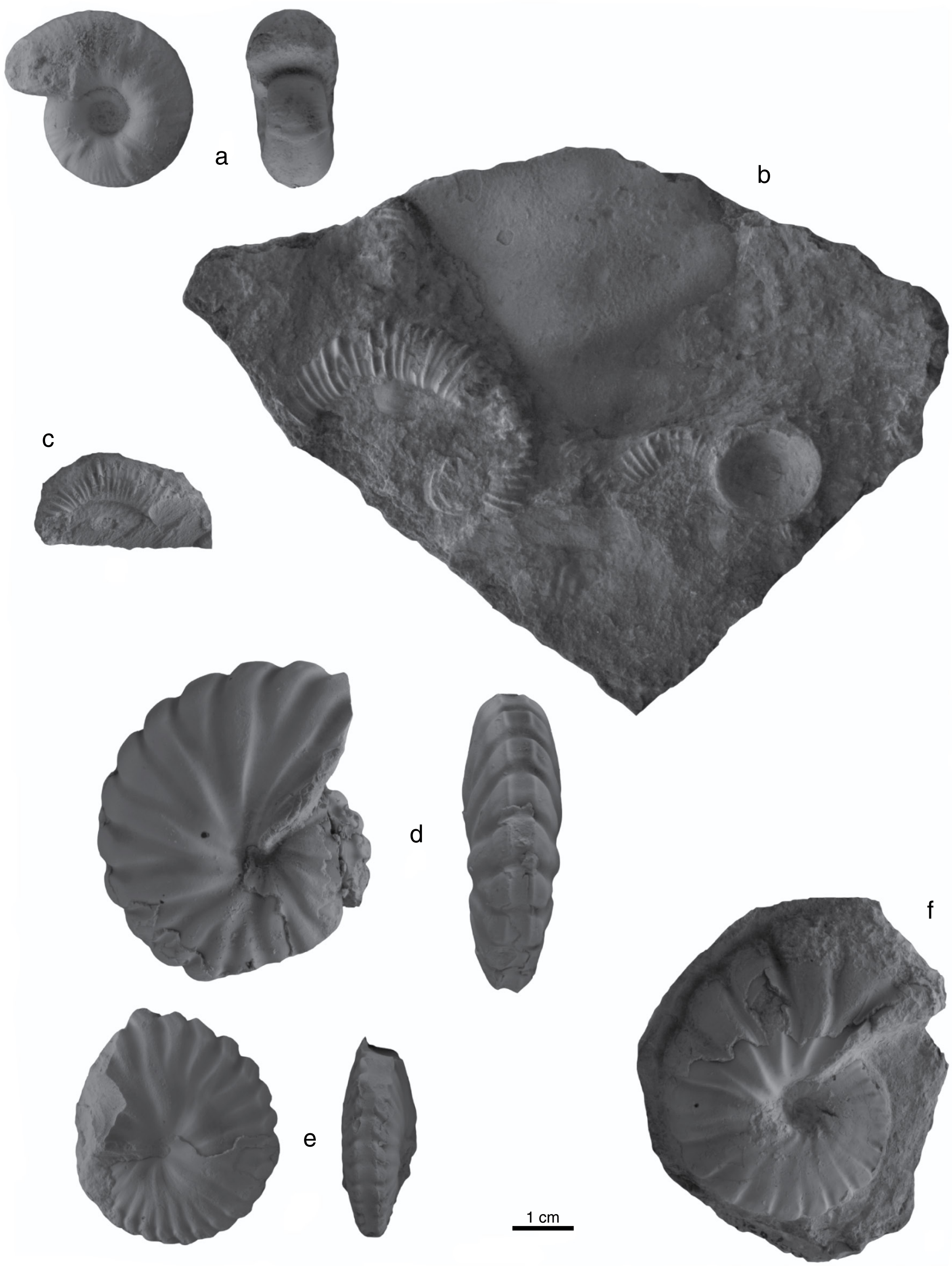

Figure 11. (a) *Valdedorsella* cf. *inca* (Forbes). Lower Barremian. Guane by Barichara (Santander province). Sample B4–2–1. **(b)** *Karsteniceras* sp., *Valdedorsella*? sp. and fish vertebrae. Lower Barremian. Guane by Barichara (Santander province). Sample B4–6. **(c)** *Karsteniceras* sp. Lower Barremian. Guane by Barichara (Santander province). Sample G–7. **(d)** *Pulchellia galeata* (von Buch). Lower Barremian. Guane by Barichara (Santander province). Sample B4–7–1. **(e)** *Pulchellia galeata* (von Buch). Lower Barremian. Guane by Barichara (Santander province). Sample B4–7–2. **(f)** *Gerhardtia veleziensis* (Hyatt). Upper Barremian. Guane by Barichara (Santander province). Sample Pt 10.

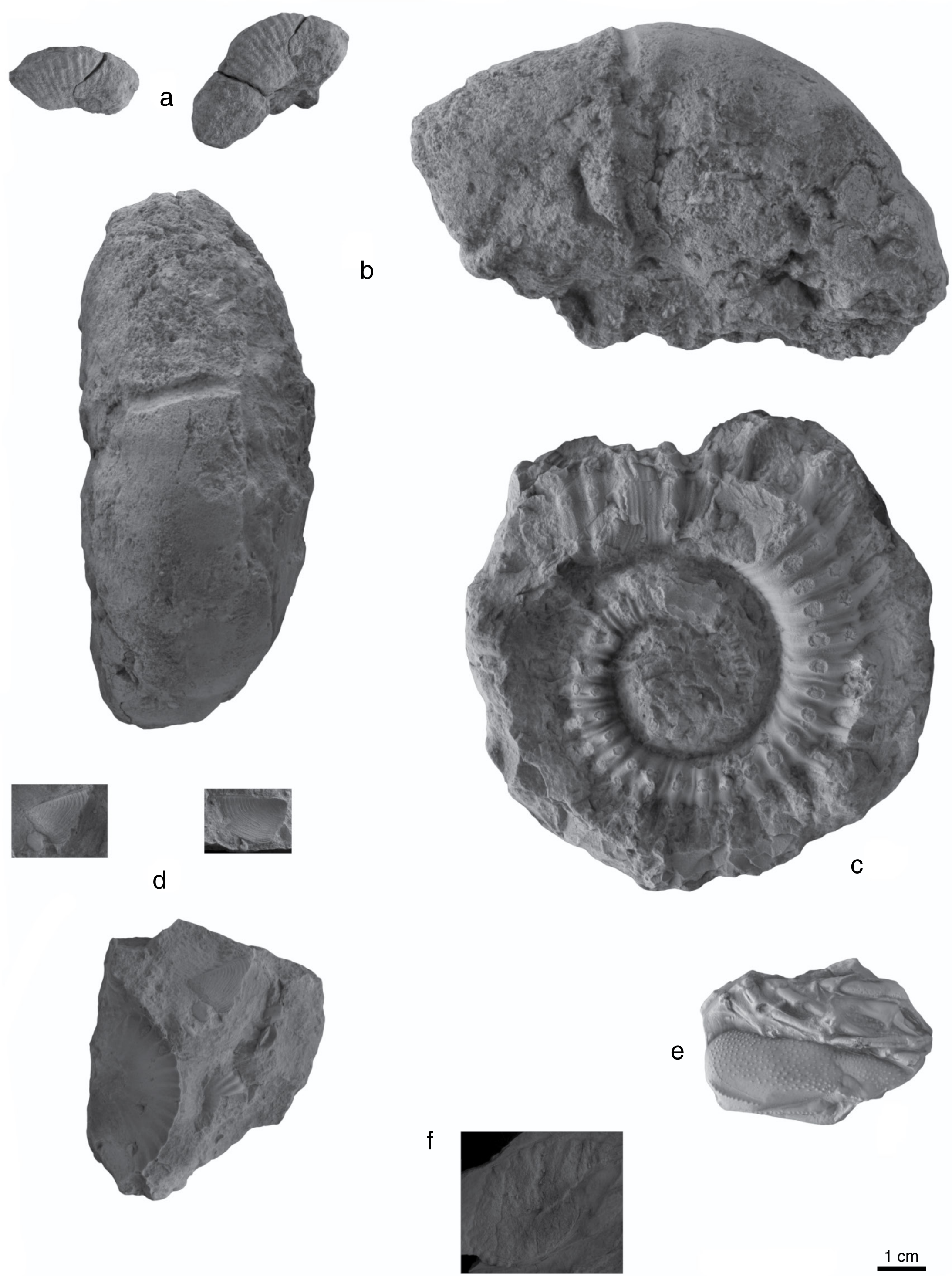

Figure 12. (a) *Pedioceras* sp. Lower Barremian. Villanueva section (Santander province). Sample VNR–1. **(b)** *Valdedorsella* or *Pseudohaploceras* sp. Lower Barremian. Barichara–Punteadero section (Santander province). Sample Pt–1. **(c)** *Paracrioceras leyvaense* (Kakabadze & Hoedemaeker). Ex situ. Lower Barremian. Villa de Leyva area (Boyacá province). Sample VL–49. **(d)** *Lamellapthycus*? sp. and *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Monsalve section by Villa de Leyva area (Boyacá province). Pp151–L. **(f)** *Atherfieldastacus*? sp. Lower Barremian. Cáqueza section (Cundinamarca province). Sample E7. **(g)** *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Punta Espada – Uribia area (La Guajira province). Sample PEY–1.

Figure 13. La Yesera section of the Paja Formation to the south of Villa de Leyva (Boyacá province).

2.2.6. Quebradagrande Complex

Botero–Arango (1963) first presented the Quebradagrande Formation along the central western margin of the Central Cordillera (La Estrella, Antioquia province); it is related to a volcano–sedimentary succession that is now recognized as the Quebradagrande Complex (González, 2001, 117). Successions such as those near Ebéjico (Antioquia province) in Loma Hermosa (Steinmann in Grosse, 1926) are included in the Quebradagrande lithostratigraphic unit (Mejía, 1984, 115), i.e., the Abejorral Formation (Valanginian – Albian) in González (1980) the San Felix Stratigraphic Tectonic Interval (Etayo–Serna 1985a, 3; Rodríguez–Rodríguez & Rojas–Ladino, 1985) and probably, the San Luis and Aquitania sedimentites (Giraldo et al., 2015) that contain Upper Jurassic and Lower Cretaceous fossils, some of which are Barremian ammonites. Steinmann in Grosse (1926) only listed "*Pulchellia* cf. *didayi*", cf. "*Desmoceras charrierianum*", and cf. "*Lytoceras subfimbriatum*".

2.2.7. Other Reported Barremian Deposits

Cretácico del Río Cañas which contains Barremian ammonites, has been reported to the south of the Oca Fault near Mingueo (La Guajira province). There, mudstones with calcareous concretions probably contain more *Nicklesia* than *Pulchellia* (cf. Colmenares et al., 2007, photography 128, 267).

In the serranía del Perijá and the Catatumbo area, the Río Negro Formation includes Barremian deposits (Julivert, 1968, 415–417; Petrash et al., 2016, Figure 2; Renz, 1959, 6; Sutton, 1946) based on the existence of Aptian ammonites in the overlying Cogollo Formation or Group in Venezuela. In the Catatumbo area (Colombia), Notestein et al. (1944) used the Tibú and Mercedes Members of the Uribante Formation, a succession that is equivalent to the Apón Formation (Sutton, 1946). Renz (1959) used the Tibú Formation, a proposition that was followed by Richards (1968) and a petroleum industry geologist. Some authors such as Julivert (1968) believe that under the Tibú Formation or Apón Formation is the underlying Río Negro Formation. Aptian ammonites are included in the Tibú or Apón Formation (Sutton, 1946) in the Catatumbo area and it is not clear if these rocks are older (Barremian) in Venezuela because of its thickening in the serranía del Perijá and Lara State (Venezuela) following Renz (1959, 9).

Between Ábrego and Gramalote (Norte de Santander province), Barremian ammonites have been reported (Bürgl, 1956, 32; Royo y Gómez in Botero–Restrepo & Sarmiento–Rojas, 1947, 36) that are probably erroneously considered to be part of the Tibú and Mercedes Formations (Vargas & Arias 1981). Some citations without illustrations related to Barremian fauna have been presented by Petters (1954) from Becerril and Pailitas (Cesar province). Langston & Durham (1955) also cited Barremian ammonites in Becerril; references that are used in Etayo–Serna et al. (1969, 232) and in this investigation to extend the Barremian deposits to north–central Colombia (Figure 24). Barremian deposits may extend to San Andrés (Santander province) based on the reported presence of Valanginian and Aptian ammonites in the "Rosablanca" Formation (cf. Acosta, 1960, 36); however, according to Vargas et al. (1976), this succession corresponds to the Tibú–Mercedes Formation.

To the north of the Upper Magdalena Valley, continental deposits of the Yaví Formation may be of Barremian age based on the transgressive sedimentary tendency from the north (central Colombia) to south within the overlying Caballos Formation sedimentites, which include Aptian ammonites in their middle part, although "*Ancyloceras* sp." have been mentioned in El Cobre Creek from San Luis (Tolima province) within an upper Barremian – lower Aptian range (cf. Etayo–Serna et al., 1969, 224). However, Durham (1946), Julivert (1968, 69) and Vega et al. (2008) indicated that they have an Aptian range.

The Muzo Formation is a recent informal lithostratigraphic unit that was introduced by Reyes et al. (2006) and includes Barremian deposits. Additionally, the El Peñon Formation of Reyes

et al. (2006, 37–40) following Ulloa (1982 in Acosta–Garay & Ulloa–Melo, 1996) represents Barremian and Aptian deposits, although this unit is correlated or equivalent to the Socotá Formation that overlies the Trincheras Formation, which is Hauterivian, Barremian, and Aptian in range. However, the El Peñón Formation of Reyes et al. (2006) overlies the Furatena Formation (Valanginian) and underlies the Capotes Formation (Albian).

3. Results

Based on this bibliographic compilation, combined with the conducted investigations and new field data presented here, correlations are proposed for the lithostratigraphic units of Colombia that include Barremian deposits. A proposed distribution of the deposits of the sub–basins that integrate the Cretaceous Colom-

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Figure 14. (a) *Psilotissotia colombiana* (d'Orbigny). Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp155–1. **(b)** *Psilotissotia malladae* (Nickles). Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp154–5. **(c)** *Psilotissotia colombiana* (d'Orbigny). Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp155–2. **(d)** *Psilotissotia malladae* (Nickles). Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp154–1. **(e)** *Psilotissotia malladae* (Nickles). Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp153B–4. **(f)** *Buergliceras buerglii* Etayo–Serna. Lower Barremian. Yuca Hill near Villa de Leyva (Boyacá province). Sample Mp00. **(g)** *Pedioceras caquesense* (Karsten). Lower Barremian. Sáchica–Tunja section near Villa de Leyva (Boyacá province). Sample Pp90–1. **(h)** *Crioceratites*? sp. Lower Barremian. Sáchica–Tunja section near Villa de Leyva (Boyacá province). Sample Pp89–5. **(i)** *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp153–1. **(j)** *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp151–2. **(k)** *Valdedorsella inca* (Forbes). Lower Barremian. La Yesera section near Villa de Leyva (Boyacá province). Sample Pp131–5. **(l)** *Acanthoptychoceras*? *trumpyi* Kakabadze & Thieuloy. Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp131–6. **(m)** *Acanthoptychoceras*? *trumpyi* Kakabadze & Thieuloy. Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp131–7. **(n)** *Acanthoptychoceras*? *trumpyi* Kakabadze & Thieuloy. Lower Barremian. Sáchica–Tunja section near Villa de Leyva (Boyacá province). Sample Pp88–5. **(o)** *Acrioceras (A.) julivertii* Etayo–Serna. Lower Barremian. Sáchica–Tunja section near Villa de Leyva (Boyacá province). Sample Pp89–6. **(p)** *Crioceratites*? sp. Lower Barremian. Sáchica–Tunja section near Villa de Leyva (Boyacá province). Sample Pp88–6.

bian Basin is also presented. The fossil fauna and the sedimentary characteristics of the Barremian deposits are the key to determine the variations in the depth of the bottom of the deposit to understand paleogeographic variations.

3.1. Correlation

As previously stated, most of the Colombian Barremian ammonites record a Tethyan influx that allows one to correlate these deposits with the western Mediterranean successions. *Psilotissotia colombiana*, *P. malladae*, *Nicklesia pulchella*, *Pulchellia communis*, "*P*". *caicedi*, *Heinzia provincialis,* and *Carstenia lindigii* are present in both areas.

The base of the Barremian is defined in the Mediterranean region by the first occurrence of *Taveraidiscus hugii* (formerly "*Spitidiscus*" *hugii* (Ooster)), and the base of the Aptian is defined by the first occurrence of *Deshayesites oglanlensis* Bogdanova (Reboulet et al., 2009, 2011, 2014, 2018). Both genera and species are not represented in Colombia, although some publications have recognized these genera but with erroneous determinations (cf. Bürgl, 1954, 1957; Etayo–Serna, 1964; Haas, 1960; Riedel, 1938) that were clarified by Etayo–Serna (1979).

Moreover, the boundaries of the Barremian and Aptian have still not been identified in Colombia. *Crioceratites* fossils have been found in the upper Hauterivian and lower Barremian (Figure 7). *Procheloniceras*, *Cheloniceras,* and *Dufrenoyia* fossils are the first representatives of Aptian deposits.

Western Mediterranean Barremian ammonite standard zones (e.g., Avram, 1983; Birkelund et al., 1984; Kakabadze, 1987, 1989; Rawson et al., 1996; Reboulet et al., 2009, 2011, 2014, 2018) may not be completely correlated to those in Colombia because of the absence of some index fossil zones.

However, it may be stated that Bürgl's subdivision of the Colombian Barremian deposits (Bürgl, 1956) in Colombia is partially accepted, although the vertical range of the ammonites of the Pulchelliidae family is mainly used to identify the lower and upper Barremian. *Pulchellia* is found after Bürgl in the upper part of the lower Barremian and in the lower part of the "middle" Barremian. Furthermore, the middle Barremian of Bürgl (1956) could not be recognized in relation to the association of *Pulchellia–Heinzia*. For Bürgl (1956), the lower limit of the upper middle Barremian was represented by the occurrence of "*Heinzia*", which nearly corresponded to the lower limit of the upper Barremian in the western Mediterranean province (Hoedemaeker & Leereveld, 1995, 219). Reboulet et al. (2009, 2011, 2014, 2018) present new interpretations related to *Heinzia* and *Gerhardtia* that changed the boundaries and biostratigraphic proposals.

The *Psilotissotia colombiana* Zone can be partially correlated to the upper *Taveraidiscus hugii* Standard Zone (Figures 6, 7), which contains the *P. colombiana* Subzone (Reboulet et al., 2009, 2011, 2014, 2018). The index species and genera of the *Kotetishvillia nicklesi* Standard Zone are not found in the Colombian Barremian deposits. The *Nicklesia pulchella* Zone is present in both areas, but the range in Colombia is broader than that in the Mediterranean standard zone. The *Kotetishvillia compressissima* Standard Zone cannot be recognized in Colombia because of the absence of the index species; however, with the inclusion of the "*Heinzia*" *communis* Horizon (Reboulet et al., 2014), it is possible to correlate it to the Colombian successions because of the presence of *Pulchellia communis* in the lower part of the Colombian *Pulchellia galeata* Zone (Figure 6). The "*Heinzia*" *caicedi* Horizon of the *Moutoniceras moutonianum* Standard Zone (Reboulet et al., 2014) can be correlated to Colombia because of the existence of "*Pulchellia*" *caicedi* (Karsten, 1858), which, until now, did not have a defined stratigraphic position in the Villa de Leyva area (Patarroyo, 2000b, 2004). However, near Vélez (Santander province), "*P*". *caicedi* (Figure 19b) was found together with *Pulchellia selecta* (Bustos, 2017) in the upper lower Barremian deposits.

To recognize the lower boundary of the upper Barremian in Colombia (cf. Patarroyo, 2000a, 2000b, 2004), we used the

Figure 15. (a) *Nicklesia nodosa* Bürgl. Lower Barremian. La Yesera section by Villa de Leyva (Boyacá province). Sample Pp131B–1–1. **(b)** *Phylloceras* sp. Lower Barremian. Sáchica–Tunja section near Villa de Leyva (Boyacá province). Pp88–9. **(c)** *Pulchellia communis* Bürgl. Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp149–1A–2. **(d)** *Pulchellia galeata* (von Buch). Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp132–4. **(e)** *Pulchellia communis* Bürgl. Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp149–1A–2. **(f)** *Karsteniceras beyrichi* (Karsten). Lower Barremian. La Yesera section by Villa de Leyva (Boyacá province). **(g)** *Pulchellia selecta* Gerhardt. Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp148B–2. **(h)** *Pulchellia fasciata* Gerhardt. Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp148A–1. **(i)** *Pulchellia fasciata* Gerhardt. Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp148A–2. **(j)** *Pulchellia hettneri* Gerhardt. Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp149–1. **(k)** *Pseudohaploceras* sp. Lower Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp149–2.

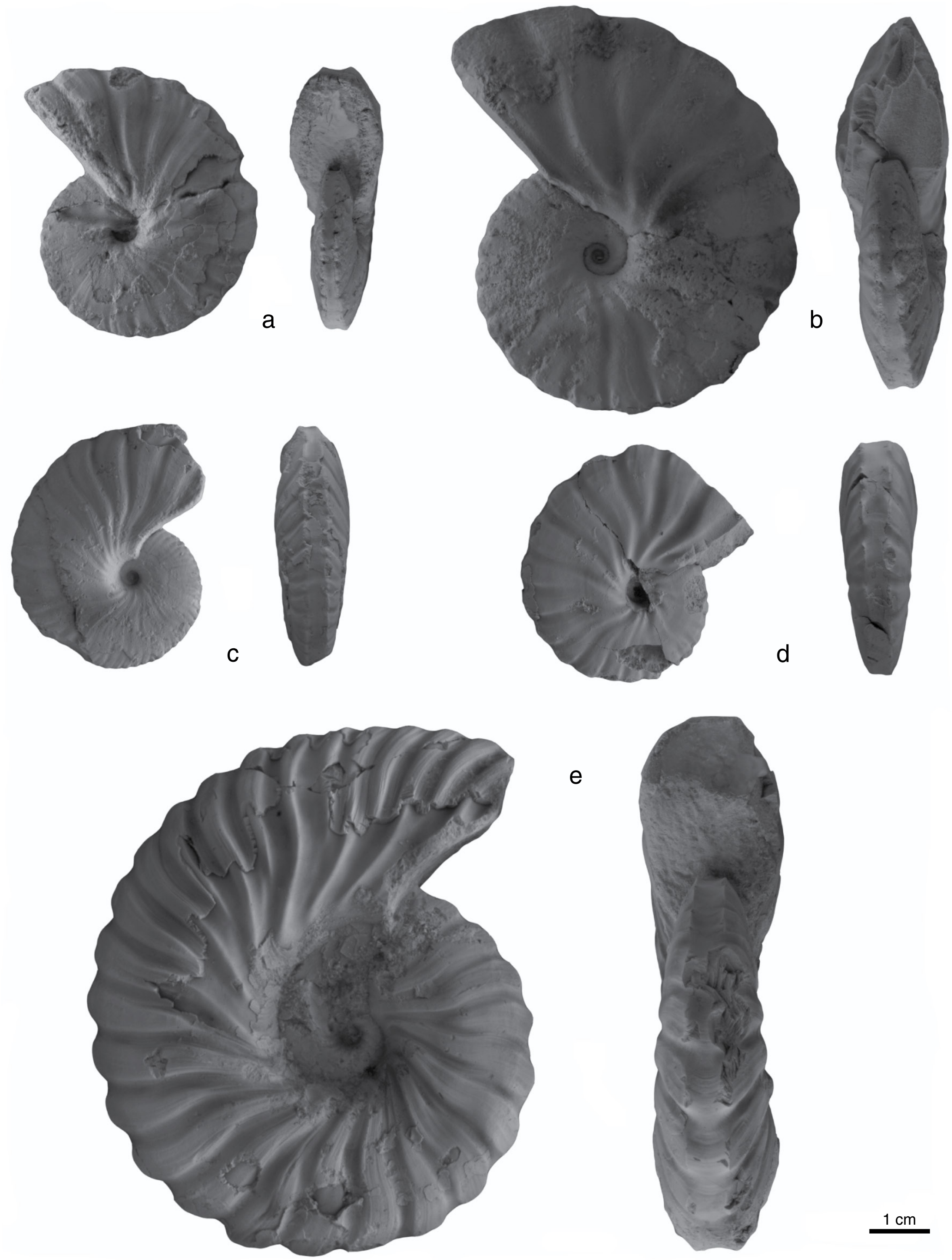

Figure 16. (a) *Gerhardtia veleziensis* Hyatt. Upper Barremian. La Yesera section by Villa de Leyva (Boyacá province). Sample Pp137–3. **(b)** *Gerhardtia veleziensis* Hyatt. Upper Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp148–1. **(c)** *Gerhardtia veleziensis* Hyatt. Upper Barremian. Monsalve section by Villa de Leyva (Boyacá province). Sample Pp146–1. **(d)** *Gerhardtia veleziensis* Hyatt. Upper Barremian. La Yesera section by Villa de Leyva (Boyacá province). Sample Pp137–4. **(e)** *Gerhardtia galeatoides* (Karsten). Upper Barremian. Santo Ecce Homo section near Villa de Leyva (Boyacá province). Sample SEH–00.

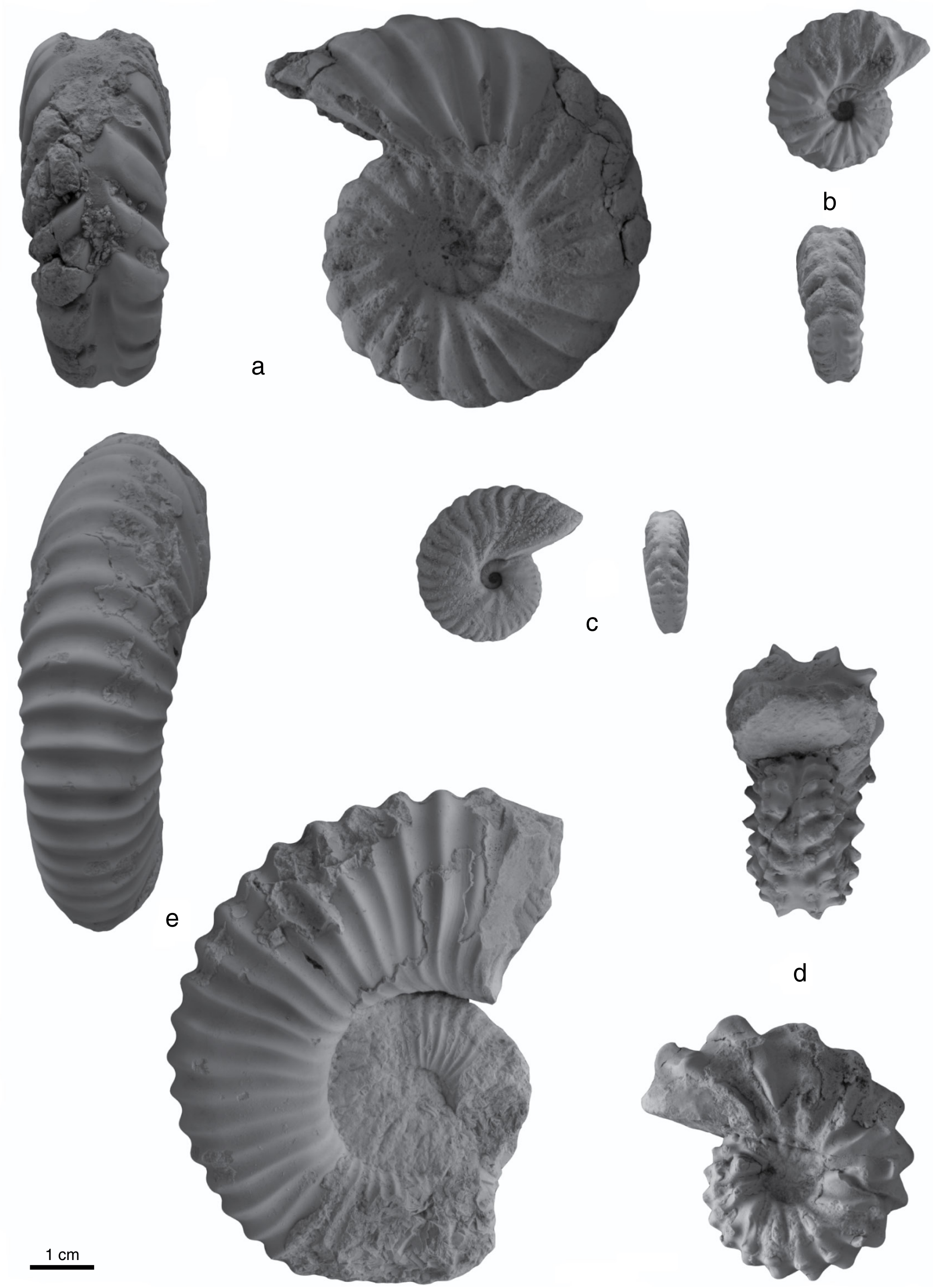

Figure 17. (a) *Heinzia colleti* Bürgl. Upper Barremian. Monsalve section by Villa de Leyva (Boyacá province). Pp146-3. **(b)** *Heinzia provincialis* (d'Orbigny). Upper Barremian. Monsalve section by Villa de Leyva (Boyacá province). Pp144-1. **(c)** *Heinzia provincialis* (d'Orbigny). Upper Barremian. Monsalve section by Villa de Leyva (Boyacá province). Pp144-3. **(d)** *Carstenia lindigii* (d'Orbigny). Upper Barremian. La Yesera section by Villa de Leyva (Boyacá province). Pp137-5. **(e)** *Colchidites breistrofferi* Kakabadze & Thieuloy. Upper Barremian. La Yesera section by Villa de Leyva (Boyacá province). Pp140-1.

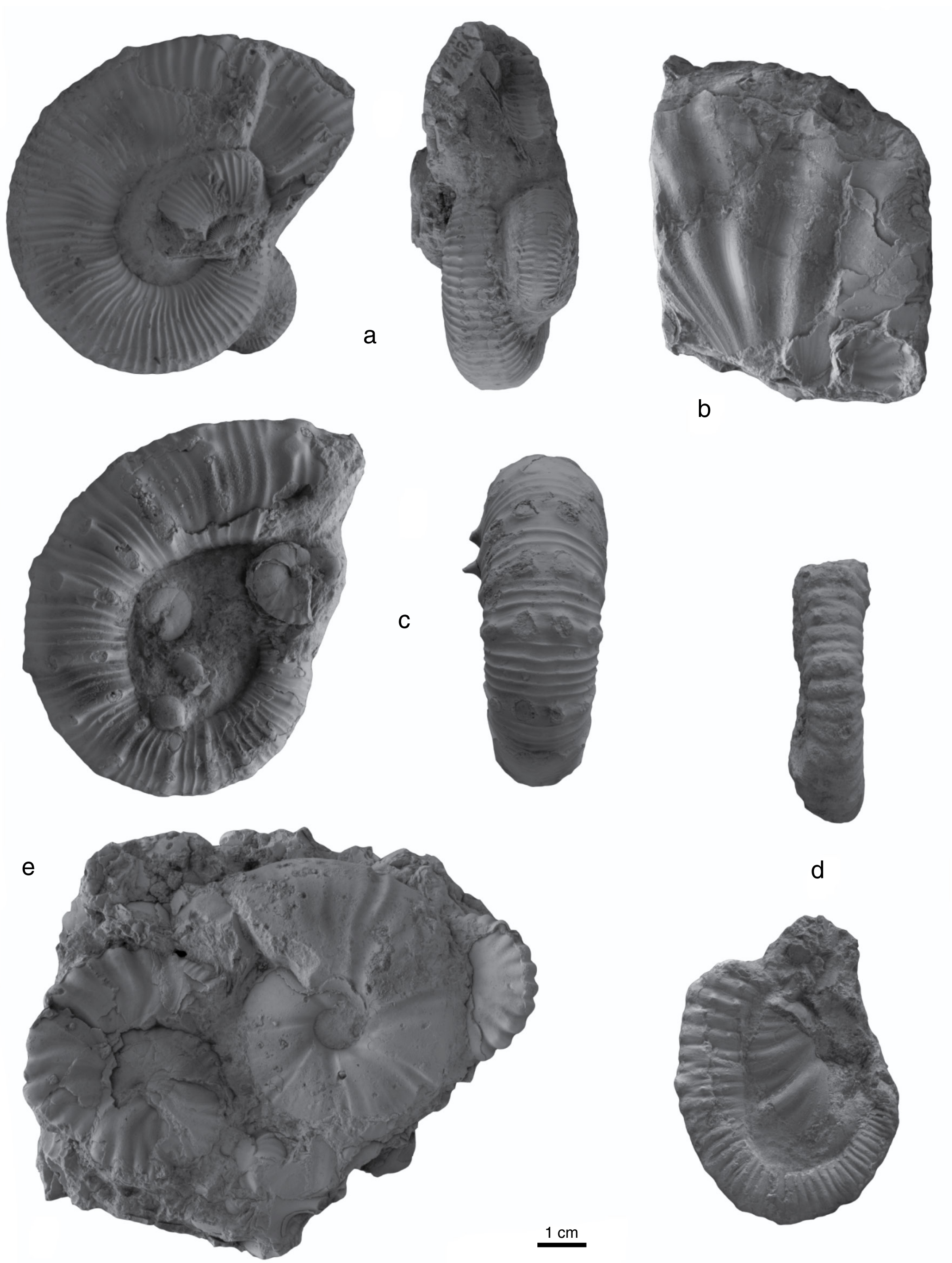

Figure 18. (a) *Pedioceras caquesense* (Karsten). Lower Barremian. Vélez–Chipatá area (Santander province). Sample VCh1. **(b)** *Buergliceras* cf. *buerglii* Etayo–Serna. Lower Barremian. Vélez–Chipatá area (Santander province). Sample VCh2. **(c)** *Paracrioceras leyvaense* (Kakabadze & Hoedemaeker). Lower Barremian. Vélez–Chipatá area (Santander province). Sample VCh3. **(d)** *Acanthoptychoceras*? *trumpyi* Kakabadze & Thieuloy. Lower Barremian. Vélez–Chipatá area (Santander province). Sample VCh4. **(e)** *Nicklesia pulchella* (d'Orbigny) and *Valdedorsella inca* (Forbes). Lower Barremian. Vélez–Chipatá area (Santander province). Sample VCh5.

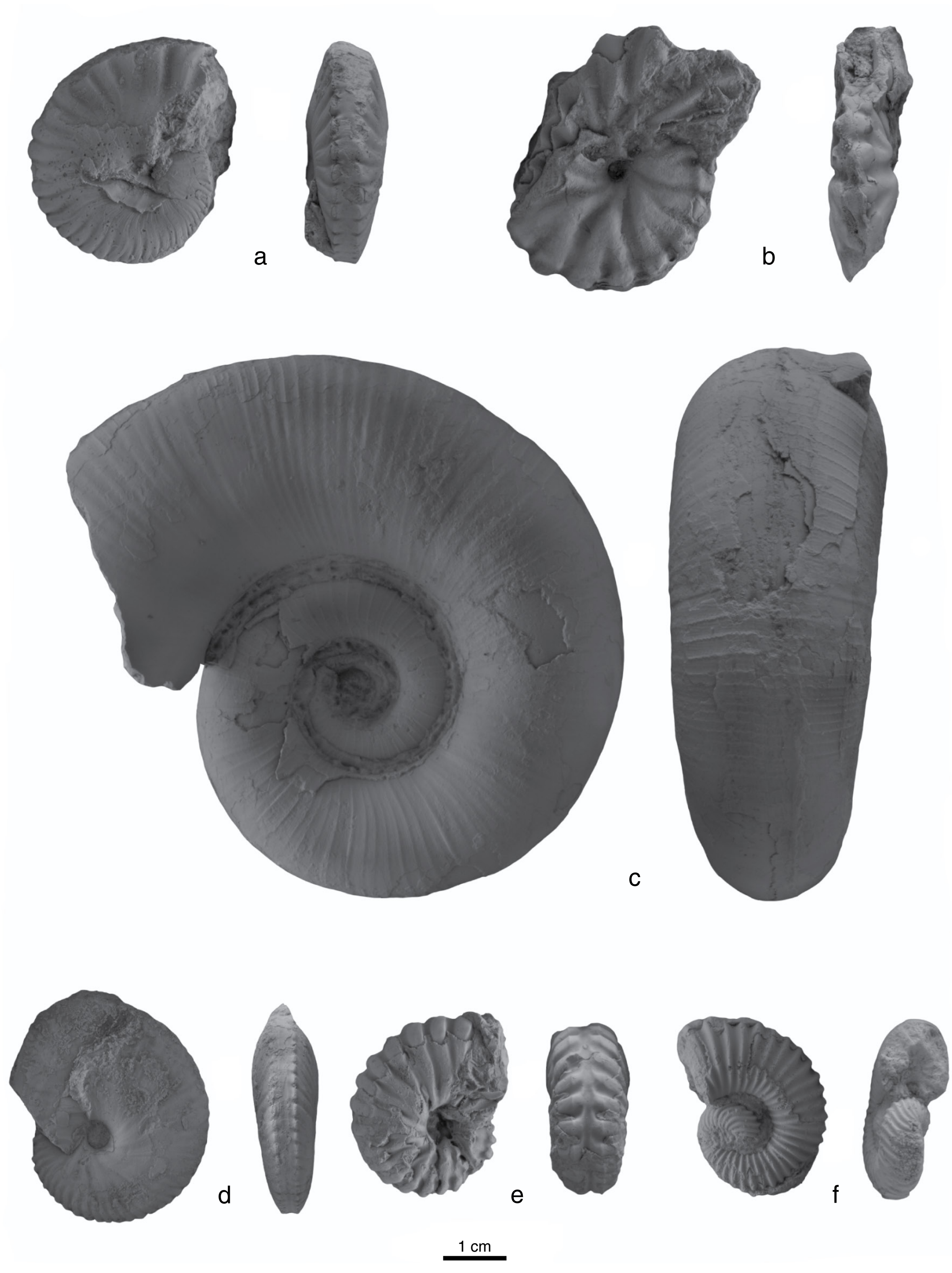

Figure 19. **(a)** *Pulchellia fasciata* Gerhardt. Lower Barremian. Vélez section (Santander province). Sample S2C9–5. **(b)** *"Pulchellia" caicedi* (Karsten). Lower Barremian. Vélez section (Santander province). Sample S2C7–1. **(c)** *Lytoceras* sp. Lower Barremian. Vélez section (Santander province). Sample S3C1–4. **(d)** *Gerhardtia veleziensis* Hyatt. Upper Barremian. Vélez section (Santander province). Sample S3C1–2. **(e)** *Carstenia lindigii* (Karsten). Upper Barremian. Vélez section (Santander province). Sample S3C1–1. **(f)** *Colchidites* sp. Upper Barremian. Vélez section (Santander province). Sample S4C5–3

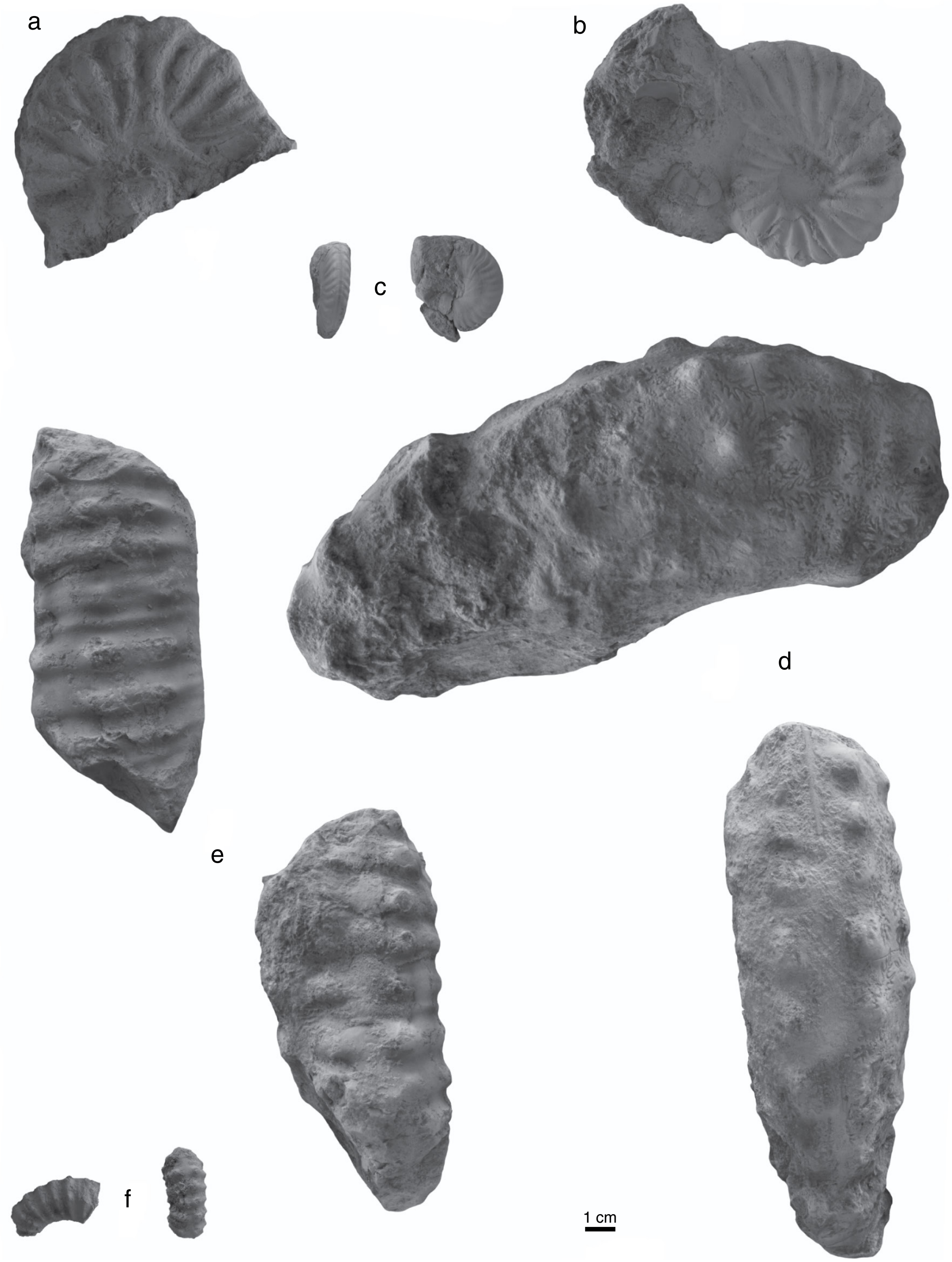

Figure 20. (a) *Gerhardtia* cf. *galetoides* (Karsten). Upper Barremian. Curití (Santander province). Sample Cr1. **(b)** *Gerhardtia galetoides* (Karsten). Upper Barremian. Curití (Santander province). Sample Cr2. **(c)** *Gerhardtia* cf. *veleziensis* Hyatt. Upper Barremian. Curití (Santander province). Sample Cr3. **(d)** *Ancyloceras*? sp. Upper Barremian. Curití (Santander province). Sample Cr4. **(e)** *Ancyloceras*? sp. Upper Barremian. Curití (Santander province). Sample Cr5. **(f)** *Kutatissites* sp. Upper Barremian. Curití (Santander province). Sample Cr6.

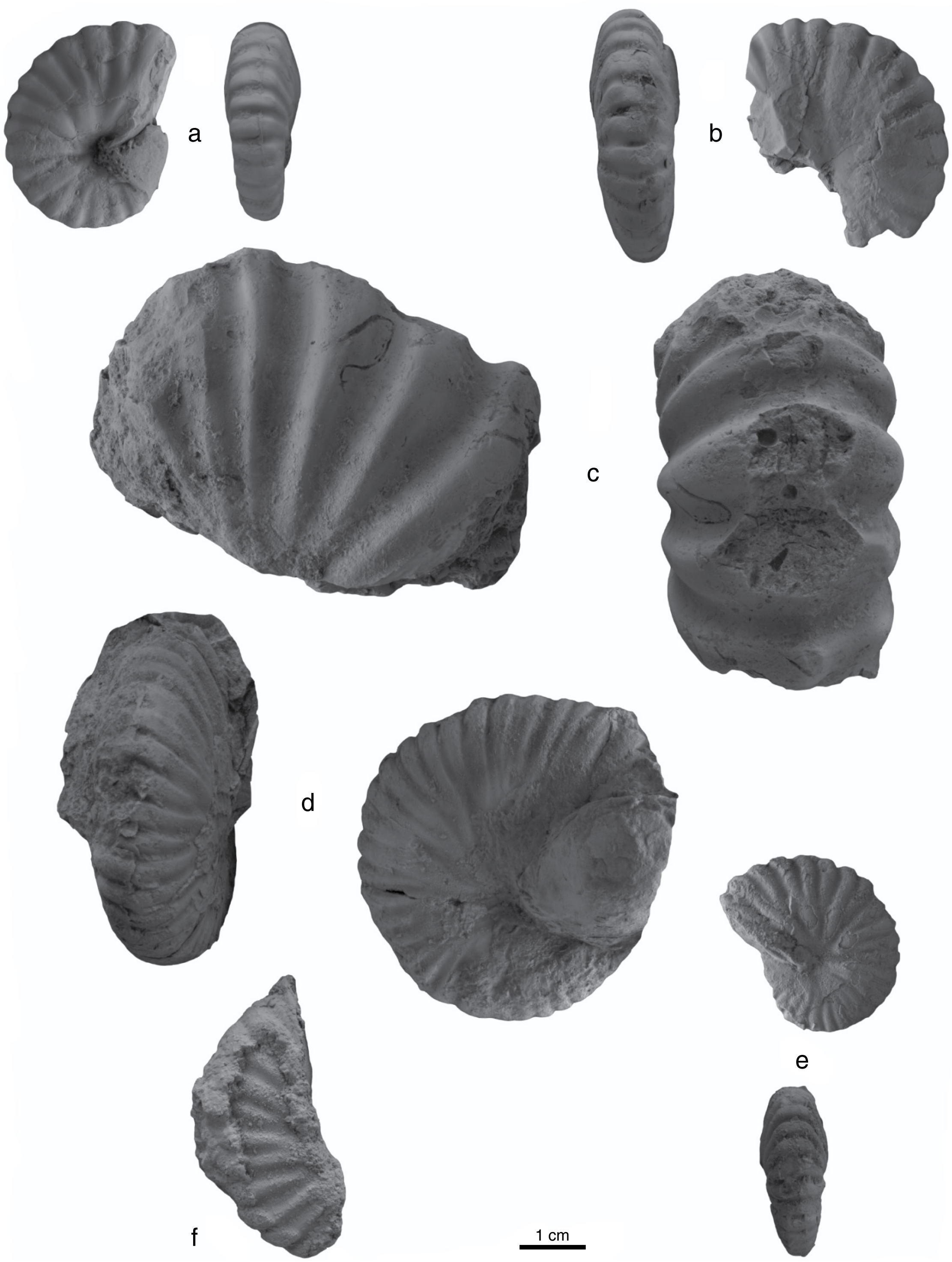

Figure 21. (a) *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Cáqueza section (Cundinamarca province). Sample C–14. **(b)** *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Cáqueza section (Cundinamarca province). Sample E5. **(c)** *Gerhardtia* cf. *galeatoides* (Karsten). Upper Barremian. Cáqueza section (Cundinamarca province). Sample E4. **(d)** *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Nocaima section (Cundinamarca province). Sample FTN–1. **(e)** *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Nocaima section (Cundinamarca province). Sample FTN–2. **(f)** *Pulchellia galeata* (von Buch). Lower Barremian. Nocaima section (Cundinamarca province). Sample FTN–3.

Figure 22. (a) *Nicklesia pulchella* (d'Orbigny). Lower Barremian. Tibasosa area (Boyacá province). Sample Sc1. **(b)** *Pedioceras caquesense* (Karsten). Lower Barremian. Firavitoba section (Boyacá province). Sample F1. **(c)**"*Crioceratites*" sp. Lower Barremian. Firavitoba section (Boyacá province). Sample F2. **(d)** *Pulchellia galeata* (von Buch). Lower Barremian. Firavitoba section (Boyacá province). Sample F3. **(e)** *Pulchellia fasciata* Gerhardt. Lower Barremian. Firavitoba section (Boyacá province). Sample F4.

Figure 23. Type locality of the Yuruma Formation. Yuruma Hill is to the right. To the left is the succession of the Hauterivian Moina Formation (La Guajira province).

first occurrence of "*Heinzia* (*Gerhardtia*) *veleziensis*" (now *Gerhardtia veleziensis*). In the western Mediterranean zone, the first occurrence of this genus is related to the *Gerhardtia sartousiana* Zone, which immediately overlies the *Toxancyloceras vandenheckii* Zone of the lowest upper Barremian. *T. vandenheckii* has not been reported clearly in Colombia because of its assignation to *Ancyloceras* (cf. Etayo–Serna, 1964; Royo y Gómez, 1945a), which may be present in Aptian deposits (Kakabadze & Hoedemaeker, 2004). This now means that it is not possible to differentiate the boundary between the lower and upper Barremian deposits in Colombia because the *Gerhardtia veleziensis* Zone in Colombia does not start at the lower Barremian limit, therefore it may be possibly to correlate it with the standard *Gerhardtia sartousiana* Zone in the western Mediterranean area (Figure 7).

Heinzia provincialis is present in Colombia and in the middle part of the *Gerhardtia sartousiana* Zone. Based on this, the "*Gerhardtia*" *provincialis* Subzone was established in the western Mediterranean area, allowing correlation of the successions in both regions.

Kakabadze (1989) reported the presence of "*Heinzia*" (*Carstenia*) *lindigii* (Karsten) in the lower and upper Barremian deposits, and Company et al. (1995) found "*H.*" (*Carstenia*) *lindigii* (Karsten) in the *Moutoniceras moutonianum* Zone from the upper lower Barremian deposits of Spain. However, in Colombia, *Carstenia lindigii* is related to the Colombian upper Barremian *Gerhardtia veleziensis* Zone.

The occurrence of *Colchidites* presented by Kakabadze (1989) and Hoedemaeker & Leereveld (1995, 219) is associated with the base of the *Imerites giraudi* Standard Zone up to the *Martelites sarasini* Standard Zone (Figures 6, 7). In this sense, the Colombian *Colchidites breistrofferi* Zone can be partially correlated to these biostratigraphic levels.

Based on study of Colombian ammonites (Paja Formation; Villa de Leyva, Sáchica, Guane, etc.), Kakabadze & Sharikadze (2004) noted that above the *Colchidites breistrofferi* Zone a level with *Pseudocrioceras anthulai* can be identified; and by ammonite composition (representatives of *Pseudocrioceras, Hemihoplites*, *Audouliceras, Kutatissites,* etc.), this level apparently corresponds to the uppermost Barremian *Pseudocrioceras waagenoides* Subzone of the standard Mediterranean scheme by Hoedemaeker & Rawson (2000).

Following the ammonite biostratigraphy, it is possible to locally correlate our Barremian marine successions (Figure 25) into the Cretaceous Colombian Basin independent of the differentiation of sub–basins (Figures 24, 26), where variable sedimentary environments developed and accumulating and preserving these successions.

Epistomina caracolla, *Platypterygius sachicarum* (Páramo–Fonseca, 1997; Maxwell et al., 2019), *Stenorhynchosaurus munozi* (Páramo–Fonseca et al., 2016), *Acostasaurus pavachoquensis* (Gómez–Pérez & Noè, 2017), *Atherfieldastacus*? sp. (cf. González–León et al., 2018), *Ceratostreon* sp., gastropods, equinoids, and wood, among others, are found together with

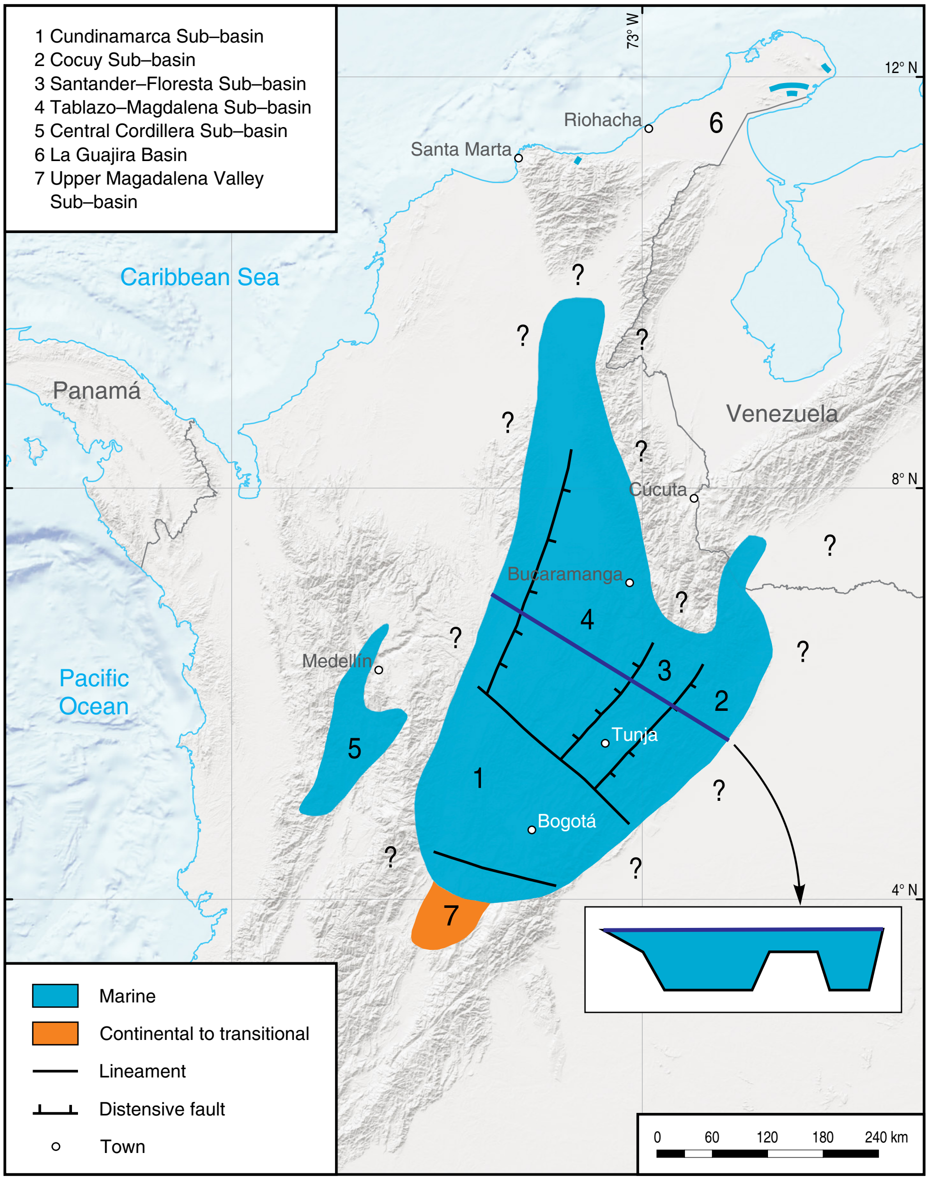

Figure 24. Colombian Barremian deposits with a geographic distribution that does not represent a real paleogeographic reconstruction. Question marks indicate absence of evidence for continental or transitional deposits.

Barremian ammonites, but some of these are not good elements to establish a correlation.

3.2. Paleogeography and Paleoecology

The Cretaceous Colombian Basin was near the equatorial zone as part of an epicontinental sea (Figures 24, 26); although some authors believe that it was a pericratonic sea, the Guayana Shield is to the east. The central Cretaceous Colombian Basin included different geological provinces, including the Amazonia Craton border (Río Negro–Juruena Province sensu Gómez et al., 2015); the Andaquí, Chibcha, Tahamí, and Calima terranes; and the lower and upper Guajira terranes, which are to the north.

Hauterivian deposits in Colombia are principally associated with a lowstand systems tract, in which there are recognized sandstones, shales, biosparites, etc. (cf. La Naveta, Útica, Murca, Rosablanca, Moina, Arenisca de Cáqueza Formations, Lutitas negras inferiores interval, Arenáceo intermedio Member of the Tibasosa Formation, etc.; Figure 25). Overlying these successions a sharp boundary appears as a transgressive surface, which can be associated with lower Barremian deposits as biomicrites, shales with concretions (Paja, Trincheras, Fómeque, and Yuruma Formations), and in some cases biosparites (Upper Calcareous Member of the Tibasosa Formation, "Rosablanca" Formation in Curití; Figure 25) occur.

In the middle stratigraphic level of the Paja Formation in the Villa de Leyva area, it is possible to recognize a bed or a

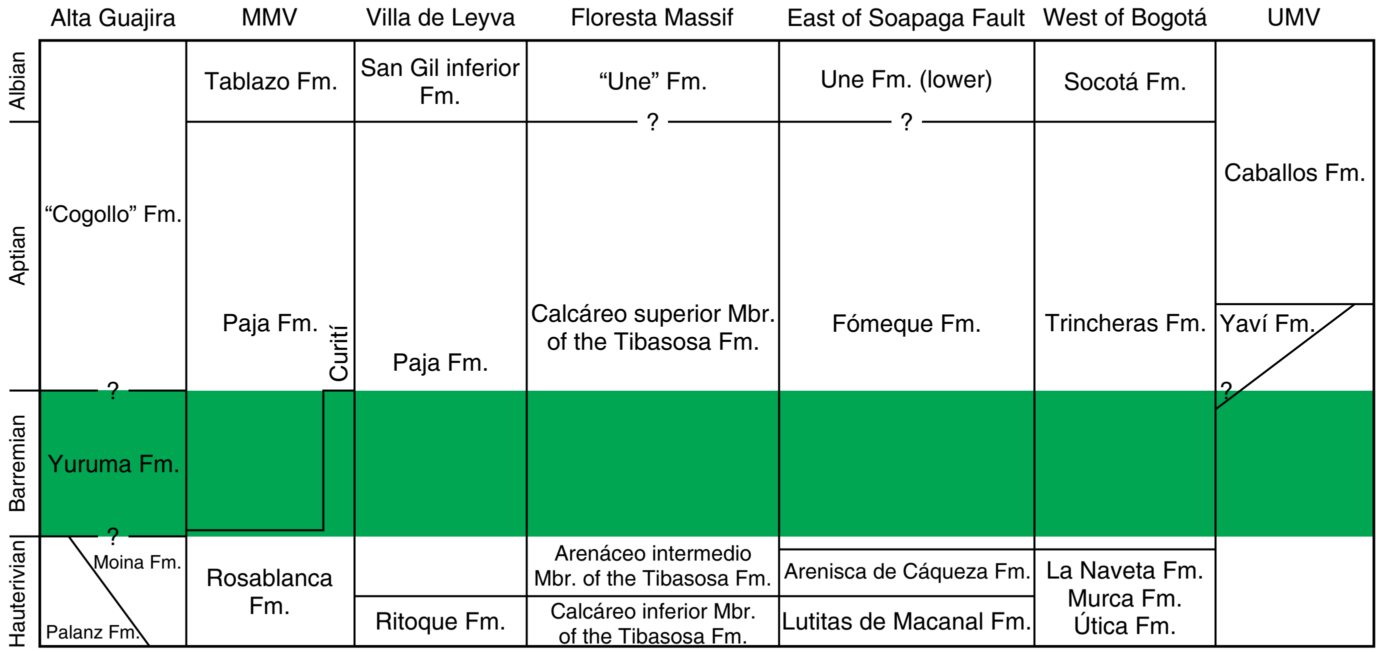

Figure 25. Colombian lithostratigraphic correlation chart of Barremian deposits.

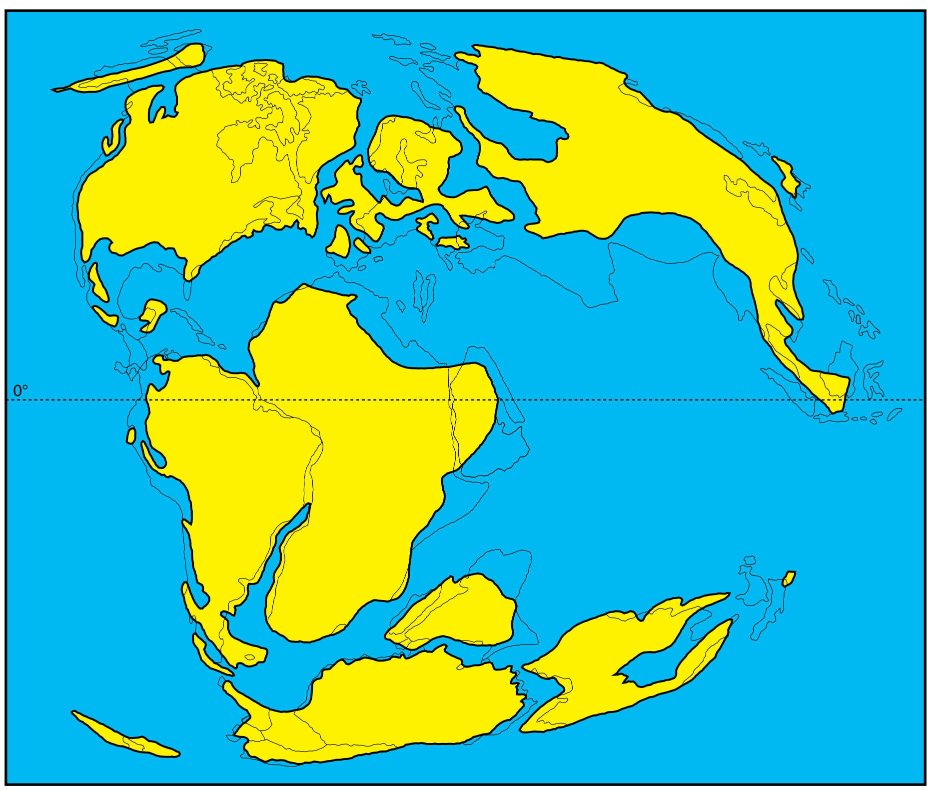

Figure 26. Barremian paleogeographic map (modified from Smith et al., 1994). Positive relief is in yellow.

bed set of biomicrites with fossil wood, ammonites, and benthic foraminifera with a chaotic disposition that has been recognized as a high–energy lower Barremian level (Patarroyo, 2009) that may be associated with a rapid and high sea level rise.

Hoedemaeker (2004) interpreted the sequences in the “monotonous Barremian succession” of Loma de La Yesera to the south of the Villa de Leyva, believing them to be missed lowstand systems tracts (hiatus) between each sequence (Hoede-

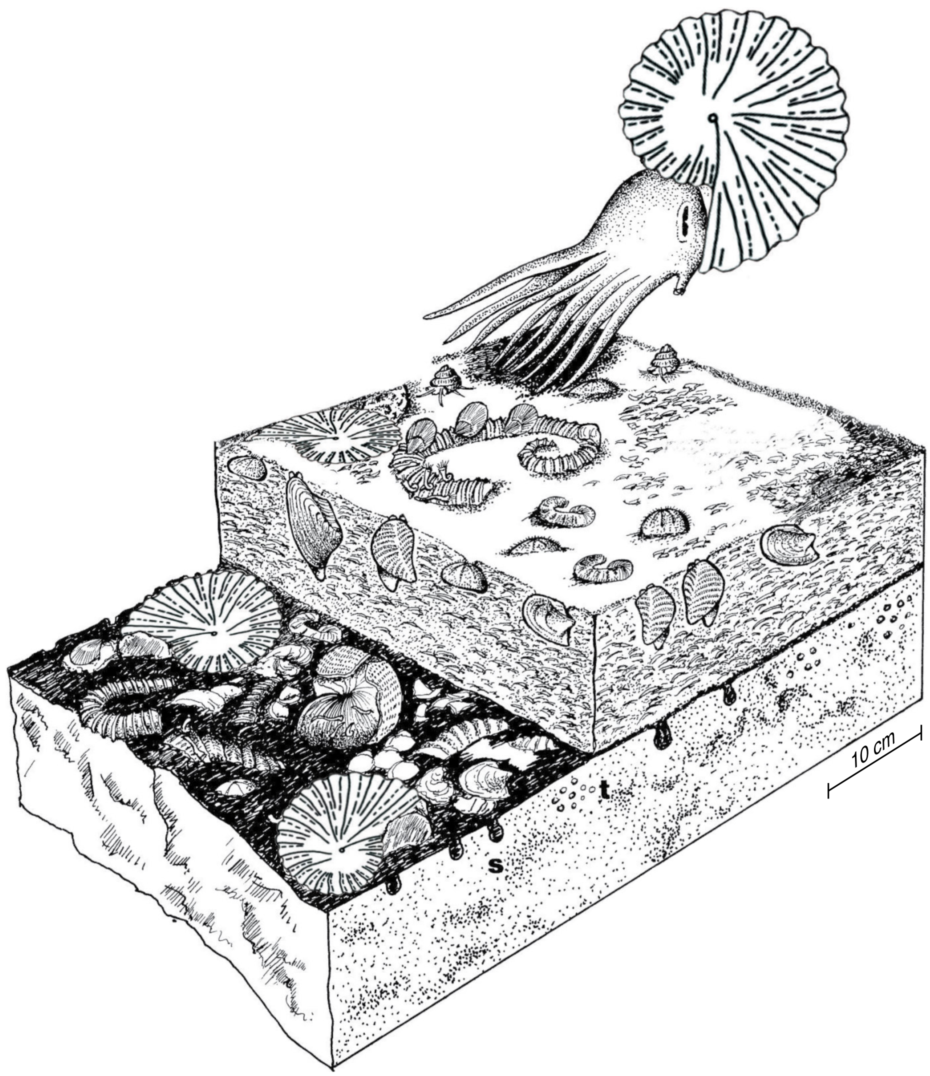

Figure 27. Diagram showing paleoecological deposit conditions of the Upper Calcareous Member of the Tibasosa Formation, "Rosablanca" Formation (Curití, Simití, etc.), and some beds of the Yuruma Formation (taken and modified from McKerrow, 1981).

maeker, 2004, Figure 3), and proposed that the sequences in Europe and Colombia "are precisely time equivalent" using biostratigraphy and stated "that the sequences are incited by global sea–level fluctuations" following the ten Barremian sequence boundaries from Río Argos in Spain (Hoedemaeker & Herngreen, 2003).

The deposits of the Upper Calcareous Member of the Tibasosa Formation contain more infaunal and epifaunal individuals than planktonic and nektonic fossils (Figure 27) in the predominantly calcareous facies of the Santander–Floresta paleo–Massif, as in some locations in the Tablazo–Magdalena (cf. "Rosablanca" Formation in Curití, Simití, etc.) Sub–basin and the La Guajira Basin in some beds of the Yuruma Formation (Figures 23, 24, 27). The disarticulation and fragmentation of thick and strong ornamented shells and carapaces is common in the biomicrites and biosparites, and the bioturbation of infaunal individuals is primarily present in the scarce muddy sediments. This type of deposit and its fossil content is characteristic of the Barremian deposits of the "Rosablanca" Formation in Curití (Santander province) or on the eastern border of the Central Cordillera (cf. Simití area following Mantilla–Figueroa et al., 2006), in some beds of the Yuruma Formation deposits (Bürgl, 1958; Renz, 1960; Rollins, 1965), in the "Cogollo" Formation (Becerril), in some beds of the Fómeque Formation, and probably between Ábrego and Gramalote near Cúcuta (Norte de Santander province).

However, the fine grained sediments (predominantly siliciclastic facies) of the Paja, Trincheras and Fomeque Formations (Figure 28) include scarce calcareous beds but more calcareous concretions with nektonic and poor benthic fauna, wood, and leaves. Thin tabular beds with a predominant plane parallel lamination can be laterally followed as a consequence of low energy regime deposits. Therefore, it is possible to interpret that these deposits were deeper (Figure 24) than those

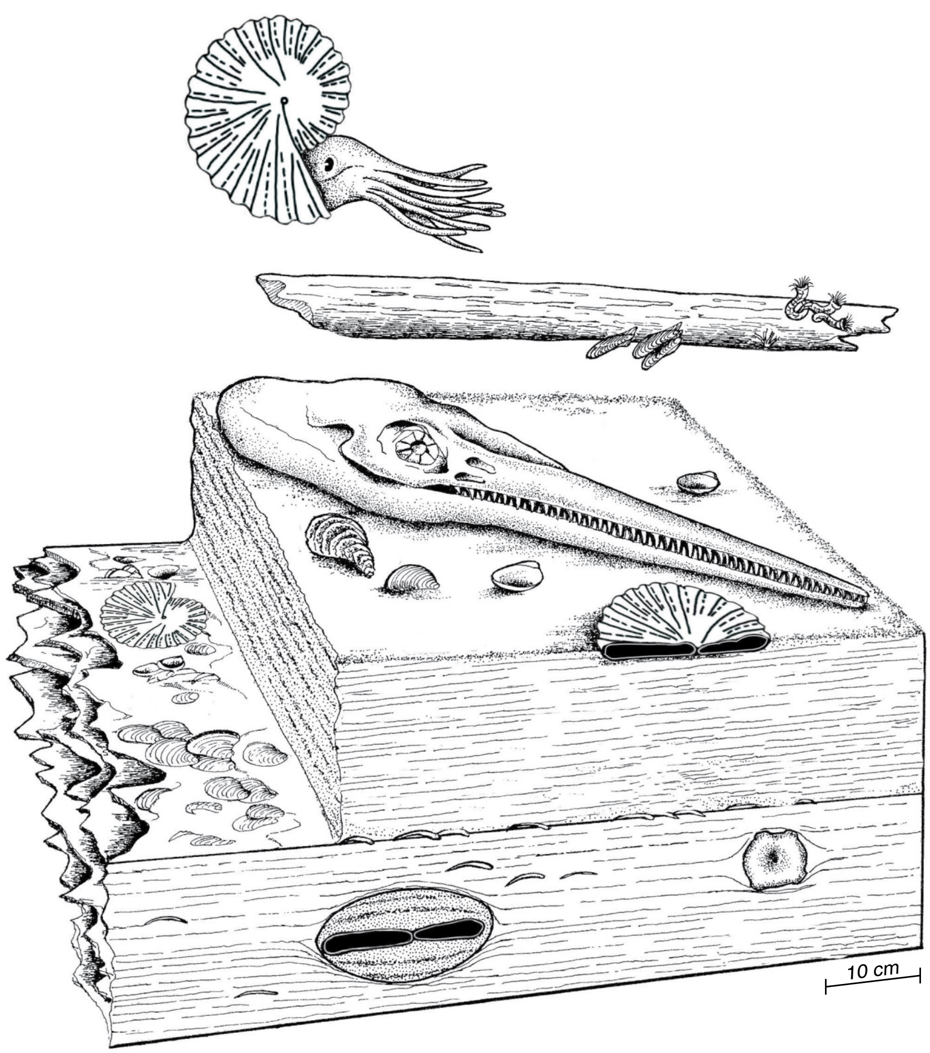

Figure 28. Diagram showing paleoecological deposit conditions of the Paja, Trincheras, and Fómeque Formations (taken and modify from McKerrow, 1981).

of the Upper Calcareous Member of the Tibasosa Formation, the "Rosablanca" Formation in Curití (Santander province) and Simití (Bolivar province), the "Cogollo" Formation in Becerril (Cesar province), and in some beds of the Yuruma Formation (La Guajira province) because the floors of the Tablazo–Magdalena, Cundinamarca, and Cocuy Sub–basins were deeper (Figure 24). However, some authors believe that the sea level during the Barremian was shallow at times (cf. Forero–Onofre & Sarmiento 1985; Hoedemaeker, 2004). Therefore, the hiatus proposition in the Colombian Barremian succession has to be proven using sufficient arguments.

3.3. Future Investigations

Chemostratigraphy, magnetostratigraphy, and sequence stratigraphy may be carefully investigated in the Barremian successions in Colombia and integrated with lithostratigraphic and biostratigraphic data to integrally understand the evolution of the Cretaceous Colombian Basin.

Interregional and intercontinental correlations can be performed to recognize biostratigraphic levels with different fossil groups, chemostratigraphic spikes, magnetic chrons, and effective hydrocarbon sources.

4. Discussion

The Paja Formation, the Barremian "Rosablanca" Formation, the Upper Calcareous Member of the Tibasosa Formation, the Yuruma Formation, and the Quebradagrande Complex are lithostratigraphic units with clear and differentiable characteristics that developed in recognized sub–basins of the Cretaceous Colombian Basin (Figures 24, 25, 27, 28) based on their sedimentological conditions, fossil contents, organic contents, thicknesses, and geographical restrictions.

Although the Barremian successions of the Fómeque and Trincheras Formations are associated with the Cundinamarca Sub–basin (Figure 24), until now it has not been possible to confirm or dispute the lateral continuity of these lithological bodies because of the absence of wells and seismic data. Therefore, they may be considered to comprise independent lithostratigraphic units.

The deposits included in the "Rosablanca" or Tibú–Mercedes Formations near Gramalote (Norte de Santander province) and San Andrés (Santander province) may be carefully investigated to clarify the paleogeographic position of the basin and to determine its actual lithostratigraphic denomination, association, and geographic distribution.

5. Conclusions

The best–investigated unit that includes marine Barremian deposits has been the Paja Formation of the Villa de Leyva area. This lithostratigraphic unit allows one to recognize other Barremian marine deposits, such as the Fómeque, Trincheras, "Rosablanca", "Cogollo", Yuruma, and "Tibú–Mercedes" Formations, as well as the Upper Calcareous Member of the Tibasosa Formation. These lithostratigraphic units differ because the developed sub–basins of the Cretaceous Colombian Basin were subject to seafloor variations, where some areas were deep and others were shallow. The surrounding continental deposits in some cases are preserved while others were eroded as a result of tectonic exhumation.

Ammonites are the most important biostratigraphic markers that can be used to correlate local sections and regional and intercontinental successions with marine Barremian deposits.

It may be possible that Colombian basin areas with continental Barremian deposits from around the Cretaceous period have been preserved, but currently, there is no biostratigraphic support.

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Explanation of Acronyms, Abbreviations, and Symbols:

FAD First apparition datum

GSSP Global Boundary Stratotype Section and Point

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