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Chapter 7

Paleontology of the Paleozoic Rocks of the Llanos Orientales Basin, Colombia

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Abstract Paleontological data on Paleozoic fossils in the Llanos Orientales Basin of Colombia are presented here. Some of these data have not been published previously and come from technical reports prepared for Oil Operators that now form part of the Servicio Geológico Colombiano library. These data contribute to a better understanding of the Paleozoic Era in Colombia. During the Devonian Period, some organisms managed to occupy terrestrial environments. Before that, life occurred exclusively in marine environments. This progression of life included terrestrial plants that produced fern spores. In the principal depocenters of the Llanos Orientales Basin, up to 6000 m of Paleozoic sedimentites are present. They include (1) Cambrian strata, determined by associations of acritarchs; (2) Ordovician strata, identified in many wells by the presence of acritarchs, chitinozoans, very well–preserved trilobites (*Jujuyaspis* spp., *Helieranella negritoensis*, and *Triarthus* sp.), and graptolites (*Janagraptus* sp., *Didymograptus extensus*, and *Dictyonema* spp.); (3) Silurian by the presence of acritarchs *Domasia bispinosa*, *Dactylofusa* spp. and *Eupoikilofusa* spp.; and finally, (4) Devonian and Carboniferous strata, which are erosional remnants that contain characteristic associations of trilete spores and acritarchs. Sedimentites from the Permian have not been in the basin, most likely because they were periods of erosion or nondeposition. The good preservation of the palynomorphs is evidence that the Paleozoic rocks in the Llanos Orientales Basin are not metamorphosed and should not be considered as the economic basement of the basin.
Keywords: *Paleozoic, palynomorphs, acritarchs, trilobites, Llanos Basin.*

Resumen Se presenta información paleontológica sobre los fósiles paleozoicos del subsuelo de la Cuenca de los Llanos Orientales de Colombia. Parte de esta información no ha sido publicada previamente y proviene de reportes técnicos preparados para Operadores Petroleros que hoy en día forman parte de la biblioteca del Servicio Geológico Colombiano. Estos datos contribuyen a comprender mejor la era paleozoica en Colombia. Durante el Devónico, algunos organismos lograron ocupar el medio terrestre. Antes de eso, la vida ocurría exclusivamente en ambientes marinos. Esta progresión de la vida incluyó plantas terrestres que producían esporas de helechos. En los principales depocentros de la Cuenca de los Llanos Orientales se presentan hasta 6000 m de rocas sedimentarias de edad paleozoica. Estas incluyen (1) estratos cámbricos, determinados con base en asociaciones de acritarcos; (2) estratos ordovícicos, identificados en un gran número de pozos por la presencia de acritarcos, quitinozoarios, trilobites muy

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bien conservados (*Jujuyaspis* spp., *Helieranella negritoensis* y *Triarthus* sp.) y graptolites (*Janagraptus* sp., *Didymograptus extensus* y *Dictyonema* spp.); (3) sedimentitas silúricas caracterizadas por la presencia de los acritarcos *Domasia bispinosa*, *Dactylofusa* spp., y *Eupoikilofusa* spp.; y finalmente, (4) estratos devónicos y carboníferos, que se presentan como pequeños remanentes erosionales y contienen asociaciones características de esporas triletes y acritarcos. Sedimentitas del Pérmico no han sido reportadas en la cuenca, muy probablemente porque fueron periodos de erosión o no depósito de sedimentos. El buen estado de conservación de los palinomorfos permite determinar que las rocas paleozoicas en la Cuenca de los Llanos Orientales no se encuentran metamorfizadas y por ello no deben ser consideradas como el basamento económico de la cuenca.
Palabras clave: *Paleozoico, palinomorfos, acritarcos, trilobites, Cuenca de los Llanos.*

1. Introduction

During the Paleozoic Era, life moved from being exclusively marine dwellers to occupying terrestrial environments, especially during the Devonian Period (Buatois et al., 1998). In the early Paleozoic, trilobites, graptolites, and crinoids dominated the oceans; however, in the late Paleozoic, terrestrial plants, fish, and reptiles already shared the world. The Paleozoic featured two of the most important events in the history of life on planet Earth: the Cambrian faunal explosion (e.g., Erwin et al., 2011; Marshall, 2006; Shu, 2008) and the Permian mass extinction, which resulted in the loss of approximately 90% of marine organisms (e.g., Burgess et al., 2014; Payne & Clapham, 2012; Raup, 1979; Raup & Sepkoski, 1982).

Multicellular organisms, which began their evolution during the Precambrian, experienced a sudden increase in quantity and diversity at the beginning of the Cambrian Period (Erwin et al., 2011). This incremental diversification of organisms strengthened life on the planet. Most of the phyla appeared within a few millions of years, and by the Cambrian Period, all the phyla that live today had appeared. The explosion of life in the Cambrian has been called "The Dilemma of Charles Darwin", who could not fit it into his theory of evolution by natural selection (Darwin, 1859).

The colonization of the continents began slowly during the late Silurian Period and became entrenched during the Devonian Period (Buatois et al., 1998). During the Carboniferous Period, the vegetation was quite abundant in large marshes, especially in Europe and North America; thus, plant remains were deposited and gave rise to thick coal deposits (e.g., Ogg et al., 2016).

During the Paleozoic, the Amazonian Craton became one of the continental nuclei (Cordani et al., 2009), around which very thick sedimentary sequences accumulated (peri–Gondwanic). These Paleozoic strata have been preserved in the Eastern and Western Venezuela (Barinas and Apure Basins) and in the Llanos, Colombia. These Paleozoic sequences form a belt that partly coincides with what Feo–Codecido et al. (1984) and Sinanoglu (1984) called the Cambrian belt.

2. Paleozoic in the Llanos Orientales Basin

In the Llanos Orientales Basin as well as in the Eastern Venezuela Basin, Paleozoic strata are widely distributed as a basal sedimentary sequence. They occur in large subsurface structures, as can be observed in the seismic lines Q–85–1275 and RLJ–2040 (Figure 1).

The correlations between Paleozoic sequences in the Llanos Orientales and Paleozoic outcrops in the Eastern Cordillera are very imprecise. The Paleozoic outcrops in the Eastern Cordillera appear as patches in the geological scheme without direct connection with the regional geology. Furthermore, the Paleozoic sedimentites of the Eastern Cordillera have suffered very strong thermal alterations, which contrasts with the weak thermal alteration of the Paleozoic sedimentites in the Llanos Orientales Basin. The scarce stratigraphic information from the Paleozoic outcrops in the Eastern Cordillera does not allow a trustworthy correlation between the two Paleozoic sequences.

Cuttings samples from the Negritos–1 well at 2698 m yielded an association of Ordovician (Tremadocian) palynomorphs (Figure 2), while at a depth of 3206.2 m, the well reached the top of the igneous–metamorphic basement. The two above mentioned surfaces can be readily followed on the seismic lines. Furthermore, with the interpretation of seismic lines, it was estimated that the thickness of the Paleozoic sedimentites in the Quenane area may exceed 6000 m (Dueñas, 2002).

On the RLJ–2040 seismic line (Figure 3) from the Eastern Venezuela Basin, it is possible to observe, highlighted in green, the unconformity at the top of the Paleozoic strata and Paleozoic structural folds due to compression. The thickness of these Paleozoic strata is ca. 2700 m, and these strata include the Carrizal and Hato Viejo Formations, which were considered by Feo–Codecido et al. (1984) to be Cambrian or older sedimentites. From Figures 2 and 3, it is possible to deduce the presence of thick coeval Paleozoic sedimentary successions in the Llanos Basin of Colombia and the Barinas Basin of Venezuela.

Traditionally, the Paleozoic sedimentites in the Llanos Orientales Basin have received little attention because they

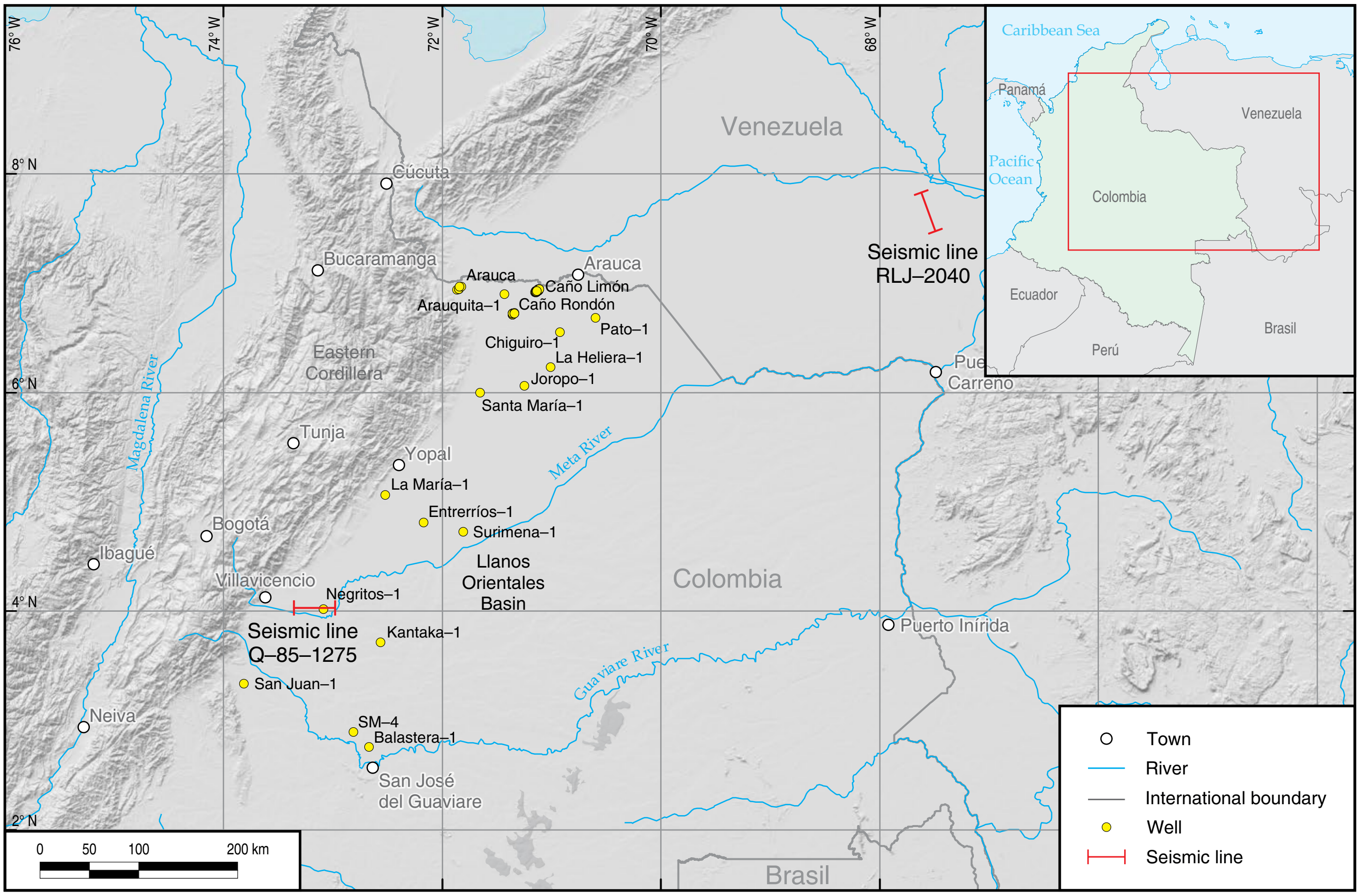

Figure 1. Locations of seismic lines Q–85–1275 and RLJ–2040 and some of the wells in which Paleozoic fossils have been recovered in the Llanos Orientales Basin.

were erroneously considered metamorphic rocks and therefore the economic basement of the basin. Many wells ended immediately after reaching the top of the Paleozoic strata that were assumed to be metamorphic. Thus, no analysis (biostratigraphic or geochemical) was carried out on the Paleozoic samples. In the central part of the basin in the Rancho Hermoso field, the color and excellent preservation of the Ordovician acritarchs indicate that these sedimentites have reached the oil generation window. Lithological and geochemical data suggest that these Paleozoic sedimentites can be interpreted as source and reservoir rocks (Arminio et al., 2013; Dueñas, 2001, 2002).

2.1. Cambrian

It has been hypothesized that during the Cambrian Period, sea level was relatively low (Haq & Schutter, 2008; Maruyama et al., 2014) and that the climate was cold. However, the climate was significantly warmer than in previous times, during which the planet suffered intense global glaciations (Maruyama & Santosh, 2008).

The Cambrian rocks are the oldest rocks in which it is possible to find abundant fossils of multicellular organisms that are more complex than sponges or jellyfishes (e.g., Shu, 2008; Zhang et al., 2014). Most of the current phyla appeared suddenly at the beginning of the Cambrian, during the greatest diversification of live in the history of the planet (Smith & Harper, 2013). Trilobites appeared in the oceans during this period (Briggs, 2015). During the Cambrian, the environment became more hospitable to life than that in the previous Ediacaran.

The Chiguiro–1 well (Figure 1) drilled in the northeastern part of the basin encountered Cambrian sedimentites at a depth between 2578.6 and 3602.7 m. Cuttings samples, as well as conventional cores, yielded Cambrian palynological associations that were characterized by the presence of *Retisphaeridium dichamerum*, *Crystallinium ovillense*, *C. cambriense*, *Satka colonialica*, *Cymatiosphaera postii*, *Trachysphaeridium laminarum*, *Leiosphaeridia* spp., *Archaeotrichion* spp., and others. These strata deposited in a marginal marine environment have been dated as middle to late Cambrian. The sedimentites between 2932.2 and 3340.6 m presented acritarch associations with *Adara matutina*, *Micrhystridinium lubomiense*, *M. notatum*,

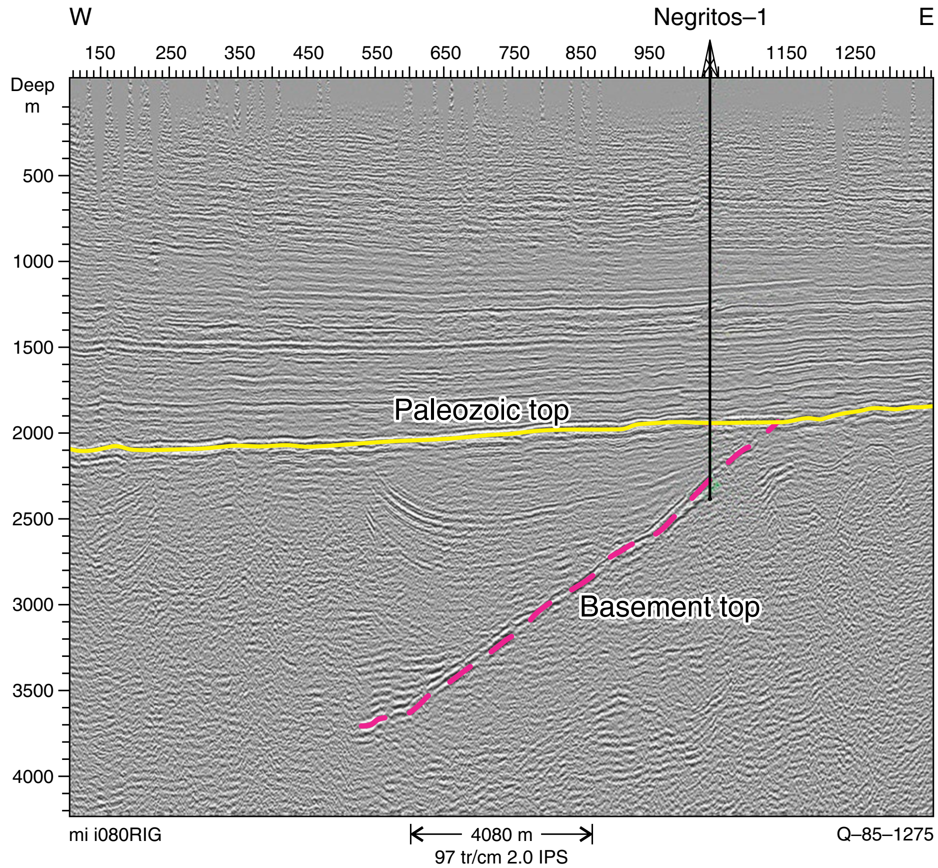

Figure 2. Seismic line Q–85–1275 including the Negritos–1 well, adapted from Dueñas (2002). The position of the top of the Paleozoic is highlighted in yellow, and the position of the top of the basement is highlighted in pink, showing a wedge of Paleozoic sedimentites that can reach 6000 m in thickness.

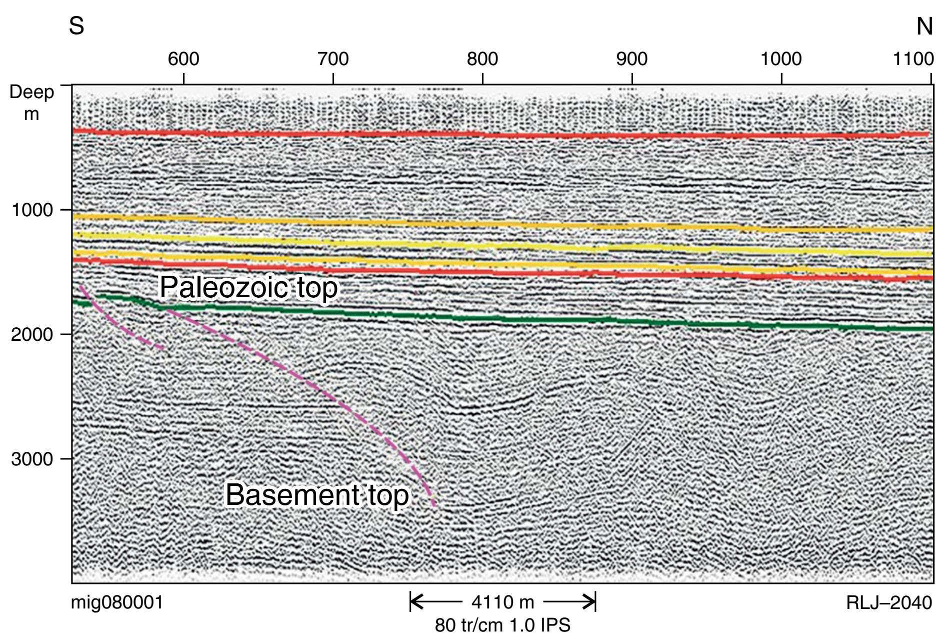

Figure 3. Seismic line RLJ–2040. The unconformity at the top of the Paleozoic sedimentites is highlighted in green and the top of the basement is highlighted in pink.

M. multipliciflagellata, *Synsphaeridium conglutinatum*, *Comasphaeridium stigosum*, *Dictyotidium birvetense*, *Cymatiosphaera ovillensis*, and *Timofeevia brevibifurcata*. This acritarch association represents a marginal marine depositional environment and indicates an early to middle Cambrian age. Associations of palynomorphs between 3368 and 3602.7 m present an abundant acritarch recovery that included *Zonhosphaeridium ovillensis*, *Tasmanites* cf. *bobrowskii*, *Micrhystridium paucoloquetrum,* and *Acrum* cf. *cylindricum* of early Cambrian age, which were deposited in a shallow marine environment. It is important to note that in deeper sedimentites, it is possible to determine the presence of Ediacaran rocks (Dueñas–Jiménez & Montalvo–Jónsson, 2020). This is the only well in the Llanos Orientales Basin in which the systematic study of samples allowed us to obtain a biostratigraphic subdivision of the Cambrian.

The Pato–1 in the northeastern side of the Llanos Orientales Basin (Figure 1) meets Paleozoic sedimentites at depths between 2133.6 and 2194.6 m. The cuttings samples between 2133.6 and 2183.9 m yielded very poor associations of palynomorphs that represent a marine depositional environment and a Cambrian age. Conventional core samples between depths of 2185.4 and 2194.6 m yielded Ediacaran palynomorphs (Dueñas, 2011). The Chiguiro–1 well and the Pato–1 well are located in the northeastern part of the basin and are related to the so–called Arauca Graben (Arminio et al., 2013).

In the Eastern Venezuela Basin, Sinanoglu (1984) reported Cambrian and shallow marine depositional environments in core samples from the Carrizal Formation. The acritarch associations from these samples are characterized by the presence of *Archaediscin umbonulata*, *Granomarginata* spp., *Skiagia ciliosa*, *S.* cf. *ornata*, *S. compressa,* and *Baltisphaeridium compressum*.

2.2. Ordovician

In several parts of the world, global sea level was significantly higher than at present (Miller, 1997), representing the greatest transgression of the Paleozoic Era (Vail et al., 1977). During the Ordovician, the Amazonian Craton was located in the Southern Hemisphere near the pole, while the Northern Hemisphere was practically an open sea (Torsvik & Cocks, 2013). The most evolved organisms that diversified during the Cambrian continued to flourish, increasing their diversity in what is known as the Great Ordovician Biodiversification Event (Webby et al., 2004).

In the Llanos Orientales Basin, a large number of wells have been drilled through Ordovician strata. Dueñas (2011) reported the presence of Ordovician acritarchs and chitinozoans in the wells and in the depths listed in Table 1. Ordovician strata occur throughout the Llanos Orientales Basin. These Paleozoic strata are characterized by an abundance of well–preserved marine palynomorphs (acritarchs and chitinozoans) and graptolites.

In a large number of old biostratigraphic reports related to the Llanos Orientales Basin, the English nomenclature was used for the Ordovician. It is therefore difficult to equate the data obtained at that time with the International Chronostratigraphic Chart (Figure 4a, 4b) (Cohen et al., 2013). Figure 4b presents a comparison between the names used in England and those used by the International Stratigraphic Commission for the Ordovician (Bergström et al., 2009).

An intense glacial period occurred in the Late Ordovician (Finnegan et al., 2011) during the Hirnantian Age at ca. 445.2 Ma (see compilation in Sheehan, 2001). That event has been associated with the mass extinction at the end of the Ordovician (Delabroye & Vecoli, 2010), which was the first of the great Phanerozoic extinctions (Sepkoski, 1996). Between 60 and 85% of taxa were lost (e.g., Delabroye & Vecoli, 2010; Isaza & Campos, 2007). No strata of glacial origin have been reported in the Llanos Orientales Basin. The Ordovician Period was very active tectonically around the world (e.g., Torsvik & Cocks, 2013), and the fact that no strata of the Upper Ordovician interval have been found in the Llanos Orientales Basin would indicate that during this interval, there was a period of erosion or nondeposition.

2.3. Silurian

The Silurian has been considered a period of erosion or nondeposition in the Llanos Orientales Basin. However, recent publications (Cediel, 2019; Kroeck et al., 2019) mention that the San Juan–1 well, drilled by Nomeco Latin America in 1988 near the serranía de La Macarena, reported the presence of *Domasia bispinosa*, a restricted Silurian acritarch, at 6905 ft.

Ecopetrol (2010) carried out palynological analysis in cuttings samples from the Paso Real–1 well, located in the southwestern part of the Llanos Basin. From 2140 to 2360 ft eight samples were prepared that yielded good acritarchs assemblages characterized by the presence of *Dactilofusa marahensis, D. oblancae*, *Eupoikiofusa cabottii*, *E. cantábrica*, *Neoveryhachium tentaculiformis*, *N. carminae*, and *Villasacapsula* spp., among others. An Early Silurian age and marine environments of deposit were assigned to this interval.

2.4. Devonian – Carboniferous

These periods cover the interval between ca. 419.2 and 298.9 Ma BP (Cohen et al., 2013). The Devonian is known as the age of the fish, in reference to the great diversification of fish during the Devonian (Benton, 1986, 2005). However, other very significant events also occurred, including the evolution of the first tetrapods, the evolution of terrestrial plants, the appearance of the first gymnosperms, and the evolution of insects and other terrestrial and marine animals. During these periods, the take-

Table 1. Wells and depth intervals where Ordovician acritarchs and chitinozoans were found. Adapted from Dueñas (2011).

Oil well name	Total deep (ft)	Terrane elevation (ft)	Latitude N	Longitude W
Almagro–1	7000	665.85	3° 54’ 7.17”	72° 39’ 45.16”
Apiay–4	12 065	950	4° 4’ 53.64”	73° 23’ 16.48”
Camoa–1	7492	936.23	3° 38’ 18.35”	73° 23’ 54.11”
Caño Cumare–1	10 583	783.62	6° 16’ 48.07”	71° 14’ 57.57”
Caño Duya–1	6196	132.89	4° 56’ 44.48”	71° 22’ 58.15”
Chavivia–1	7824	653.61	4° 13’ 25.41”	72° 13’ 52.81”
Cocli SW–1	940	647.29	4° 20’ 6.92”	71° 22’ 56.11”
Entrerrios–1	10 714.1	557.51	4° 48’ 12.97”	72° 10’ 28.6”
Fuente–1X (1821–1X)	9168	966.01	3° 29’ 12.16”	73° 36’ 41.46”
Guariloque–3	6900	479	4° 51’ 56.25”	71° 36’ 54.13”
Joropo–1	8200	328.79	6° 4’ 17.01”	71° 14’ 20.02”
Kantaka–1	5676	603	3° 42’ 40.39”	72° 33’ 53.22”
La Cabaña–1	17 569	650.03	5° 2’ 51.67”	72° 27’ 15.53”
La Heliera–1	8961	439.69	6° 14’ 47.95”	70° 59’ 57.36”
Metica–1	11 171	548.42	4° 16’ 4.64”	72° 50’ 34.41”
Negritos–1	10 452.5	611.87	4° 1’ 40.43”	73° 4’ 36.07”
Ocelote–1	4817	649.39	4° 16’ 25.24”	71° 35’ 40.92”
Rancho Hermoso–1	10 710	169	5° 1’ 45.39”	71° 58’ 33.6”
Rondón–1	8134	447	5° 27’ 14.57”	71° 14’ 30.62”
S–11A (X–R–859) (STRAT–XR–11A)	8544	531.99	4° 29’ 57.23”	71° 37’ 14.75”
San Juan–1	6965	1459.97	3° 22’ 35.71”	73° 51’ 07.65”
Santa María–1	13 582	857.19	6° 0’ 31.1”	71° 38’ 34.17”
Simón–1	5780	558.6	4° 30’ 21.22”	71° 37’ 12.98”
Surimena–1	8324	486.24	4° 44’ 21.75”	71° 47’ 58.2”
Valdivia–1	6120	642.68	3° 54’ 34.41”	72° 39’ 36.85”

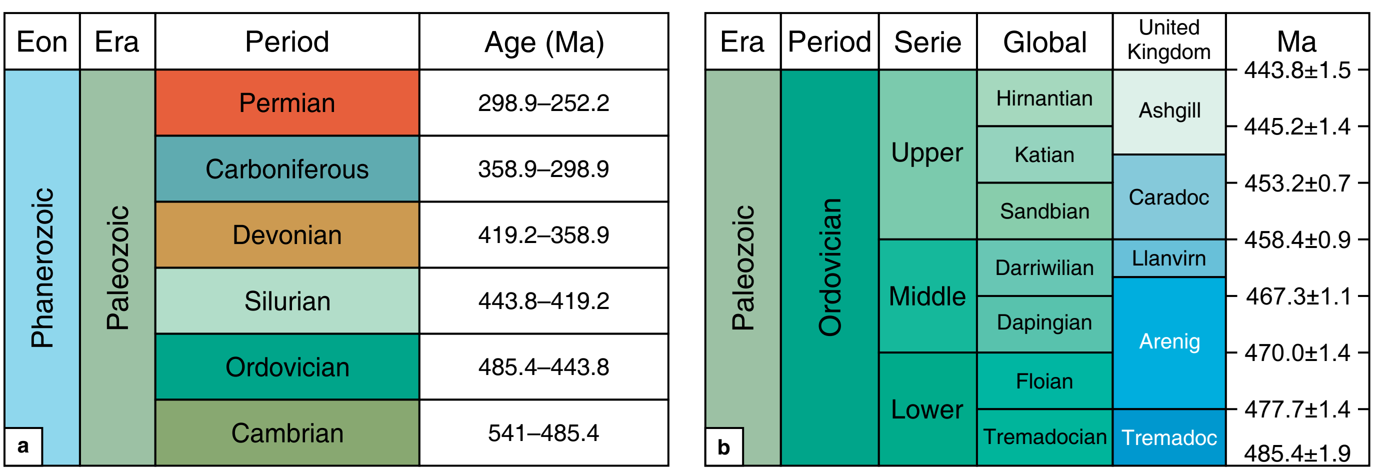

Figure 4. (a) Chronostratigraphic subdivisions of the Paleozoic. Adapted from Cohen et al. (2013). **(b)** Correlation between the current global nomenclature of 2017 and the classic Ordovician nomenclature used in the United Kingdom. Adapted from Bergström et al. (2009).

over of the continents by complex life forms progressed (e.g., Algeo & Scheckler, 1998; Davies & Gibling, 2013).

In the Llanos Orientales Basin, Dueñas (2001, 2011) reported the presence of Devonian strata in the Balastera–1, SM–4 (728.5–899.2 m), Surimena–1 and La Maria–1 (5273–5291.3 m) wells.

The cuttings samples from La María–1 well presented poor associations of trilete spores of genera *Archaeozonotriletes* and *Grandispora* with acritarchs of genera *Veryhachium*, *Baltisphaeridium,* and *Micrhystridium*, which indicates a Devonian age (Dueñas, 2001, 2011).

A very rich and diverse association of palynomorphs was recovered from cuttings samples of the SM–4 well (Figure 1), within which the presence of trilete spores and their association with acritarchs are highlighted (Dueñas & Césari, 2005, 2006). The analysis of these associations of palynomorphs permits assigning an early Carboniferous age to the 579.7–713.2 m interval, whereas from 713.2 to 906.8 m, the sedimentites drilled were assigned a Late Devonian age (Dueñas & Césari, 2006). The early Carboniferous trilete spores assemblages included *Spelaeotriletes triangulus*, *Retusotriletes crassus, Prolycospora rugulosa*, *Indotriradites dolianitii*, *Auroraspora solisorta*, *Apiculiretusispora multiseta*, *Vallatisporites* sp., *Anapiculatisporites concinnus*, *Grandispora spiculifera*, *Verrucosisporites nitidus*, *Spelaeotriletes pretiosus*, among others. Devonian trilete assemblages included *Teichertospora torquata*, *Ancyrospora* sp., and *Hystricosporites* spp. The SM–4 well is the only published record in which sedimentites of early Carboniferous age have been identified in the Llanos Orientales Basin. The assemblages of trilete spores and acritarchs are illustrated in Figures 5, 6, 7.

In the Eastern Venezuela Basin, Sinanoglu (1984) mentioned that several samples from the post–Carrizal unit in the Carrizal–1X, Tres Matas–X, Socorro–1X, Hato Viejo–1X, and Zuata–1X wells yielded palynological associations of Late Devonian – early Carboniferous age, which allows a correlation with the Llanos Orientales Basin of Colombia, based on the age reported for the SM–4 well.

2.5. Permian

No Permian strata have been reported in the Llanos Orientales Basin. The Permian was probably a time of nondeposition or intense erosion.

3. The Fauna of La Heliera–1 and Negritos–1 Wells

La Heliera–1 well is located in the northwestern part of the Llanos Orientales Basin (Figure 1). The well was drilled by Mobil Oil Company in 1959. After traversing 2499.4 m of a sequence of Cenozoic and Cretaceous strata, it cut Paleozoic strata, reaching a total depth of 2729.5 m (Dueñas, 2011). Within the Paleozoic sequence, two conventional cores were taken, the first one (Core 1) between depths of 2618.8 and 2628 m and the second (Core 2) between depths of 2728 and 2731.3 m. Several cuttings samples and some fragments of conventional cores were analyzed using palynological methods, yielding associations of acritarchs, chitinozoans, and graptolites of Early Ordovician age (Tremadocian) (Dueñas, 2011).

Core 1 showed an abundant, diverse, very well–preserved, and identifiable association of trilobites, some dendroid graptolites, and an orthid brachiopod of Early Ordovician age (Tremadocian). Core 2 did not present any identifiable fauna, but fragments of this core yielded Tremadocian palynomorphs.

Eighteen black–and–white photographs of the Tremadocian fauna have been preserved, some of which are reproduced in this chapter (Figures 8, 9, 10). The complete set of photographs and related reports have been delivered to the Museo Geológico Nacional José Royo y Gómez for preservation and consultation. The photographs of this fauna were analyzed by Clark (1960) and by Hughes (1980, 1982), who identified the trilobite *Jujuyaspis keideli* and the graptolite *Dictyonema* sp. It is necessary to bear in mind that several of the names assigned by Clark (1960), Hughes (1980, 1982), and Baldis et al. (1984), to the fauna found in these cores require a taxonomic revision based on modern criteria. The taxonomic revision of these names, as well as the description of new material found in the geological museum of the Universidad Nacional de Colombia, is in progress.

Based on the information from La Heliera–1 and Negritos–1 wells, Ulloa et al. (1982) presented a stratigraphic subdivision of the Ordovician in the Llanos Orientales Basin, establishing the Negritos Formation, which is composed of the Casanare, La Heliera, and Puerto López Members. In the Negritos–1 well, between depths of 2781 and 2784 m, a core (Core 2) was cut in which it was possible to identify the presence of the trilobite *Triarthus* sp., the graptolites *Janagraptus* sp. and *Didymograptus extensus,* and the brachiopod *Acotetra* sp. Dueñas (2011) reported that cuttings samples from Negritos–1 well located between 2743.2 and 3200.4 m presented quite abundant, well–preserved, and diverse associations of palynomorphs (acritarchs and chitinozoans) and graptolites of Tremadocian age deposited in near–shore sea environments.

Using black–and–white photographs of Core 1 from La Heliera–1 well, Baldis et al. (1984) determined the presence of the new genus *Helieranella*, which is represented by the species *Helieranella negritoensis* and the presence of the dendroid graptolite *Dictyonema flabeliforme*. They also described the trilobites *Jujuyaspis truncaticonis* and *Jujuyapsis colombiana* as new species. The association of trilobites allows a Tremadocian age to be

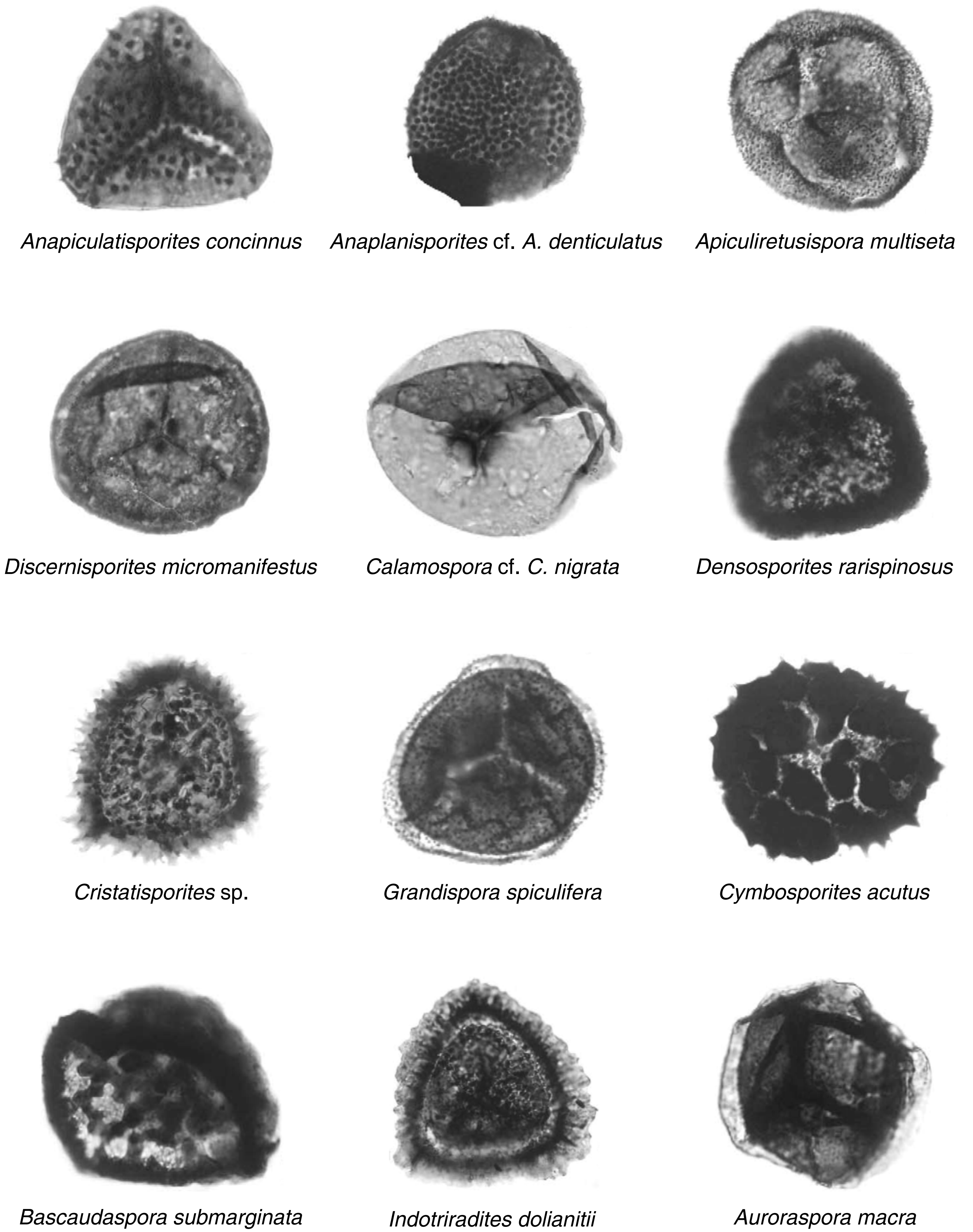

Figure 5. Carboniferous palynomorphs, SM–4 well. Adapted from Dueñas & Césari (2006). Photos without scale.

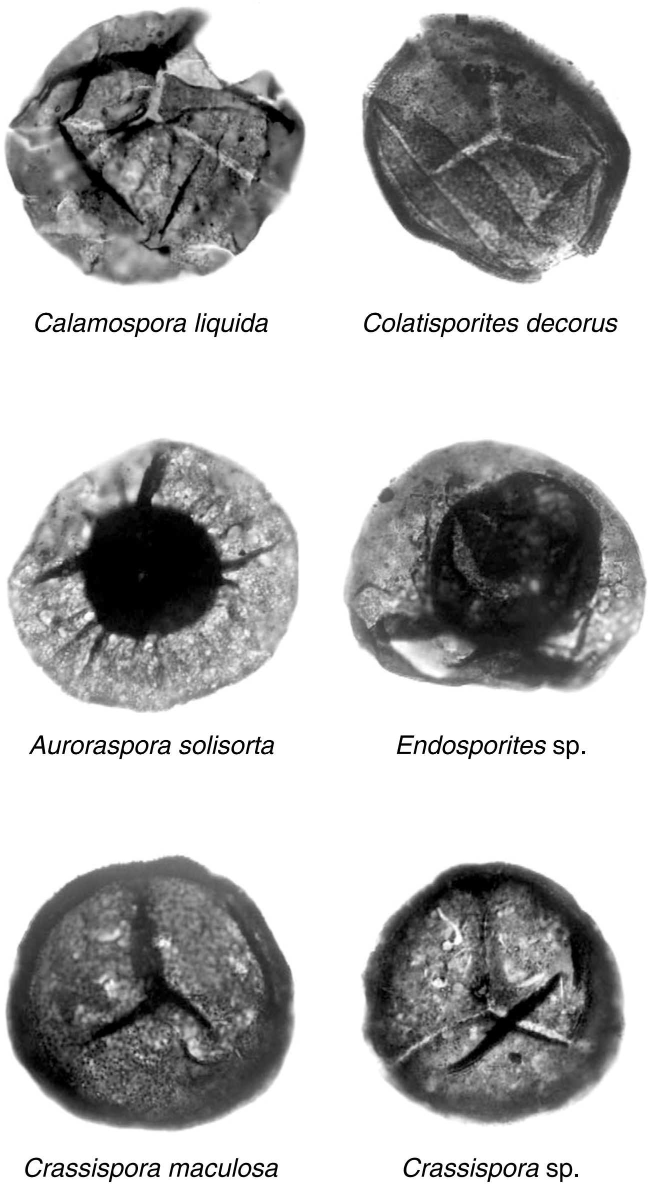

Figure 6. Carboniferous palynomorphs, SM–4 well. Adapted from Dueñas & Césari (2006). Photos without scale.

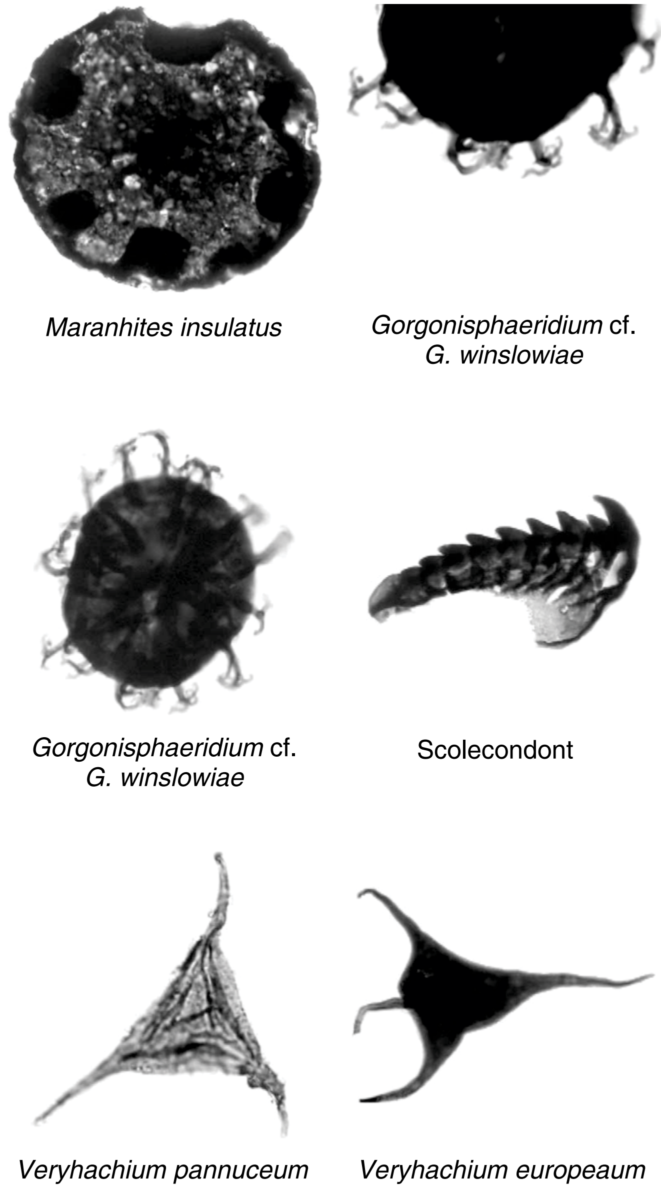

Figure 7. Carboniferous palynomorphs, SM–4 well. Adapted from Dueñas & Césari (2006). Photos without scale.

assigned to Core 1. Sedimentites from the Core 1 are part of La Heliera Member of the Negritos Formation, according to Ulloa et al. (1982), who also mentioned that sedimentites containing *Jujuyaspis* occur in Argentina, Bolivia, Colombia, and Venezuela.

4. Acritarchs and Other Fossils from the Araracuara Region

In the western part of the serranía de Chiribiquete, south of the Llanos Orientales Basin near the town of Araracuara, along the Caquetá River (Figure 11), a sandy section with sporadic presence of clays crops out and can reach more than 500 m in thickness (Bogotá, 1982; Galvis et al., 1979). From these clays, Théry et al. (1986) recovered abundant and well–preserved assemblages of acritarchs, including *Cymatiogalea cuvillieri*, *Acanthodiacrodium angustum*, *Acanthodiacrodium constrictum*, *Acanthodiacrodium lineatum*, *Acanthodiacrodium simplex*, *Acanthodiacrodium* cf. *filiferum*, *Veryhachium valiente*, *Veryhachium trispinosum*, *Dactylofusa striata*, *Leiosphaeridia* spp., *Priscogalea cortinula*, *Priscotheca raia*, *Dasydiacrodium eichwaldi*, *Dasydiacrodium* spp., and *Polygonium spinosum*. Théry et al. (1986) assigned an Ordovician age and a near–shore depositional environment to these sedimentites. This publication became the first record of acritarch associations in

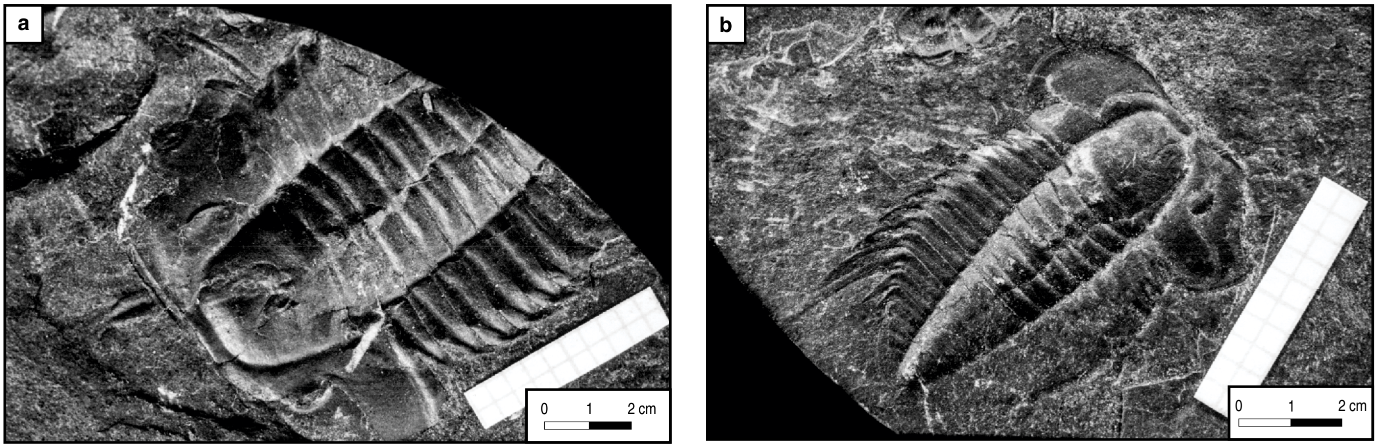

Figure 8. Tremadocian trilobites from La Heliera–1 well. **(a)** and **(b)** *Jujuyaspis truncaticonis.*

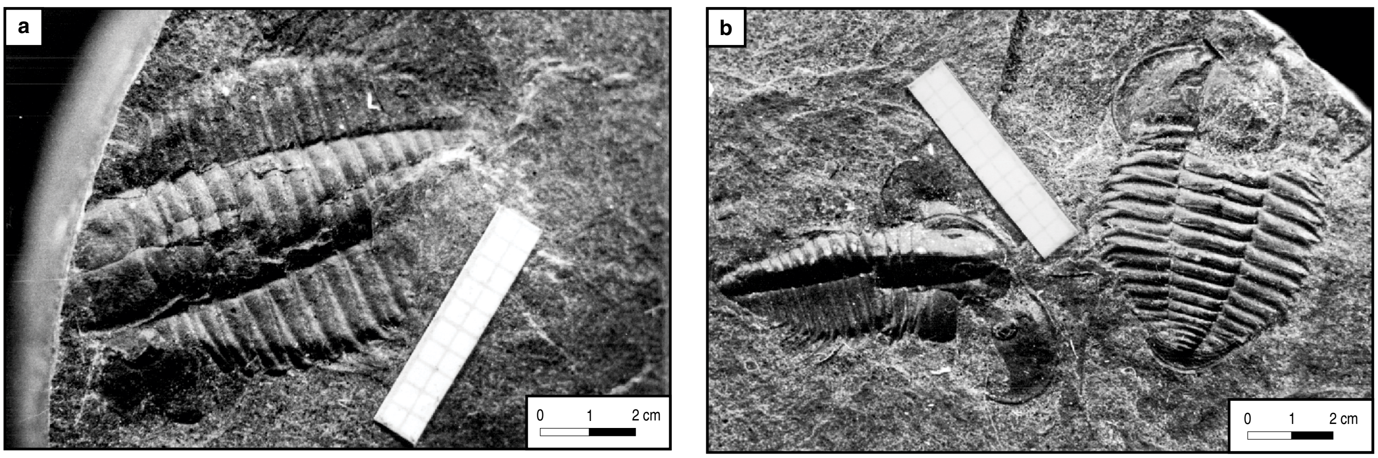

Figure 9. Tremadocian trilobites from La Heliera–1 well. **(a)** *Jujuyaspis colombiana*. **(b)** From left to right: *Jujuyaspis truncaticonis* and *Jujuyaspis colombiana*.

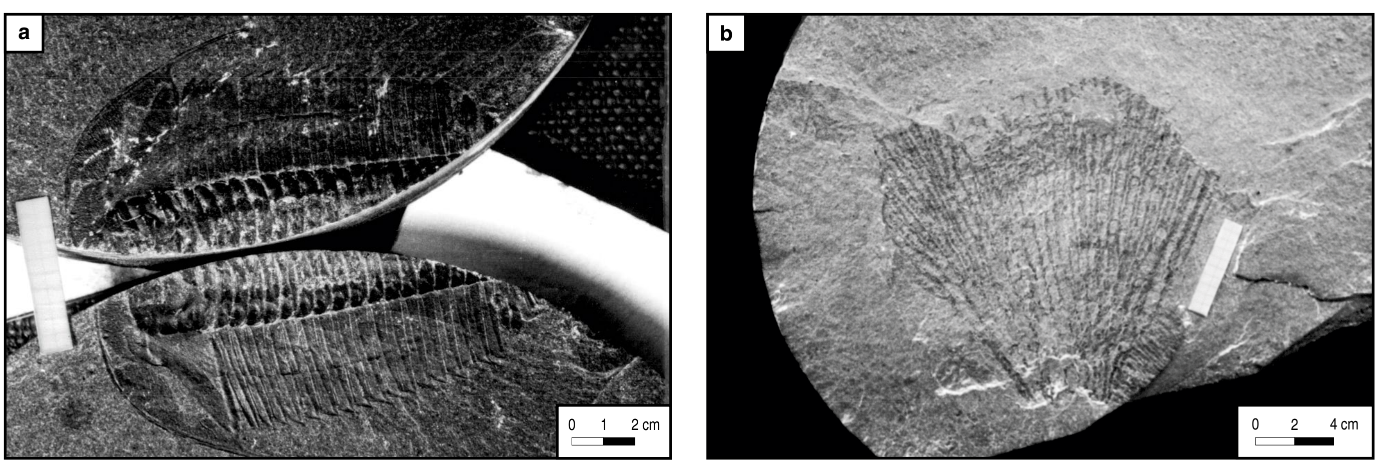

Figure 10. Tremadocian fossils from La Heliera–1 well. **(a)** Trilobite *Helieranella negritoensis* and **(b)** graptolite *Dictyonema flabelliforme.*

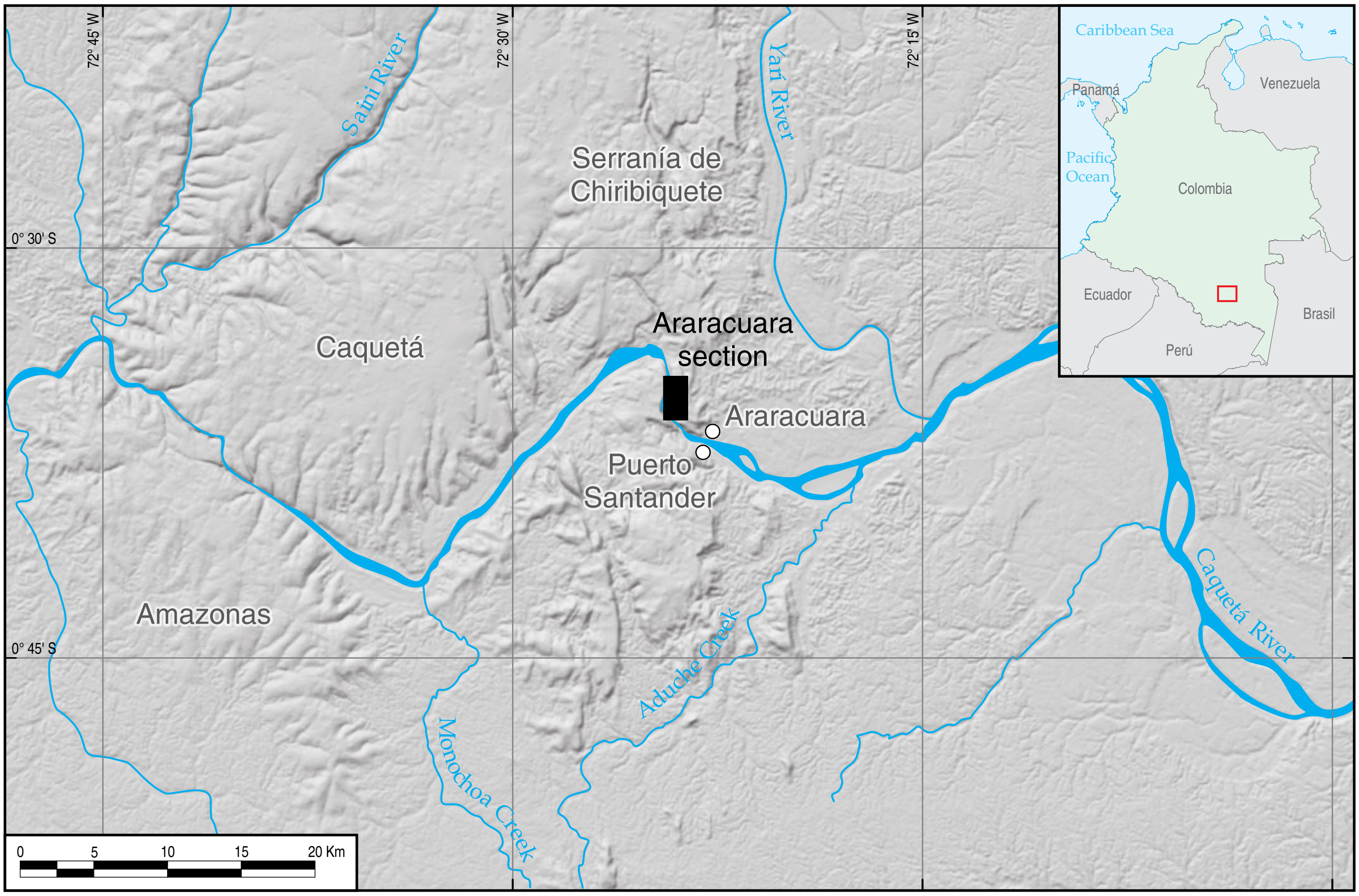

Figure 11. Location of the Araracuara section on the banks of the Caquetá River, northwest of the town of Araracuara. Adapted from Théry et al. (1986).

Colombia. Some of the cited palynomorphs are illustrated in Figure 12. Currently, this sandy section is being studied by the Servicio Geológico Colombiano.

Associations of Ordovician acritarchs, similar to those reported by Théry et al. (1986), were reported by Martinez–Aguirre (2011) in the Kantaka–1 well and by Dueñas (1984) in the Entrerrios–1 well, which are located in the central part of the Llanos Orientales Basin.

It is important to mention that Mojica & Villarroel (1990) reported an Arenigian age for the Araracuara region based on the presence of trace fossils (*Cruziana*, *Skolithos*, *Fucoides*), inarticulate brachiopods (*Lingulella*? sp.), and unidentified trilobites. Unfortunately, the exact locations of these samples are not known. These fossil remains allow us to correlate the Araracuara sandy section with the Negritos Formation in the Negritos–1 well.

5. Discussion and Conclusions

Despite the inclusion of these paleontological data, especially palynomorphs and some trilobites, information remains very fragmented for establishing biostratigraphic subdivisions of the Paleozoic in the Llanos Orientales Basin of Colombia. The associations of acritarchs, chitinozoans, and trilobites have allowed the Cambrian, the Silurian, the Devonian, and the Carboniferous Periods, and and the Early and Middle Ordovician Epochs to be differentiated in wells in the Llanos Orientales Basin. However, Upper Ordovician and Permian strata have not been reported in the basin, apparently due to periods of erosion or no sedimentation.

The Paleozoic sequence of the Llanos Orientales Basin of Colombia may show thicknesses of up to 20 000 ft of organic–rich marine mudstones, which cover thousands of square kilometers. These sedimentites are characterized by the presence of very well–preserved palynomorphs that indicate moderate thermal alteration. The presence of hydrocarbons in the Paleozoic sedimentites has been detected in several wells. The Paleozoic strata in the Llanos Orientales Basin can be considered an oil exploration target.

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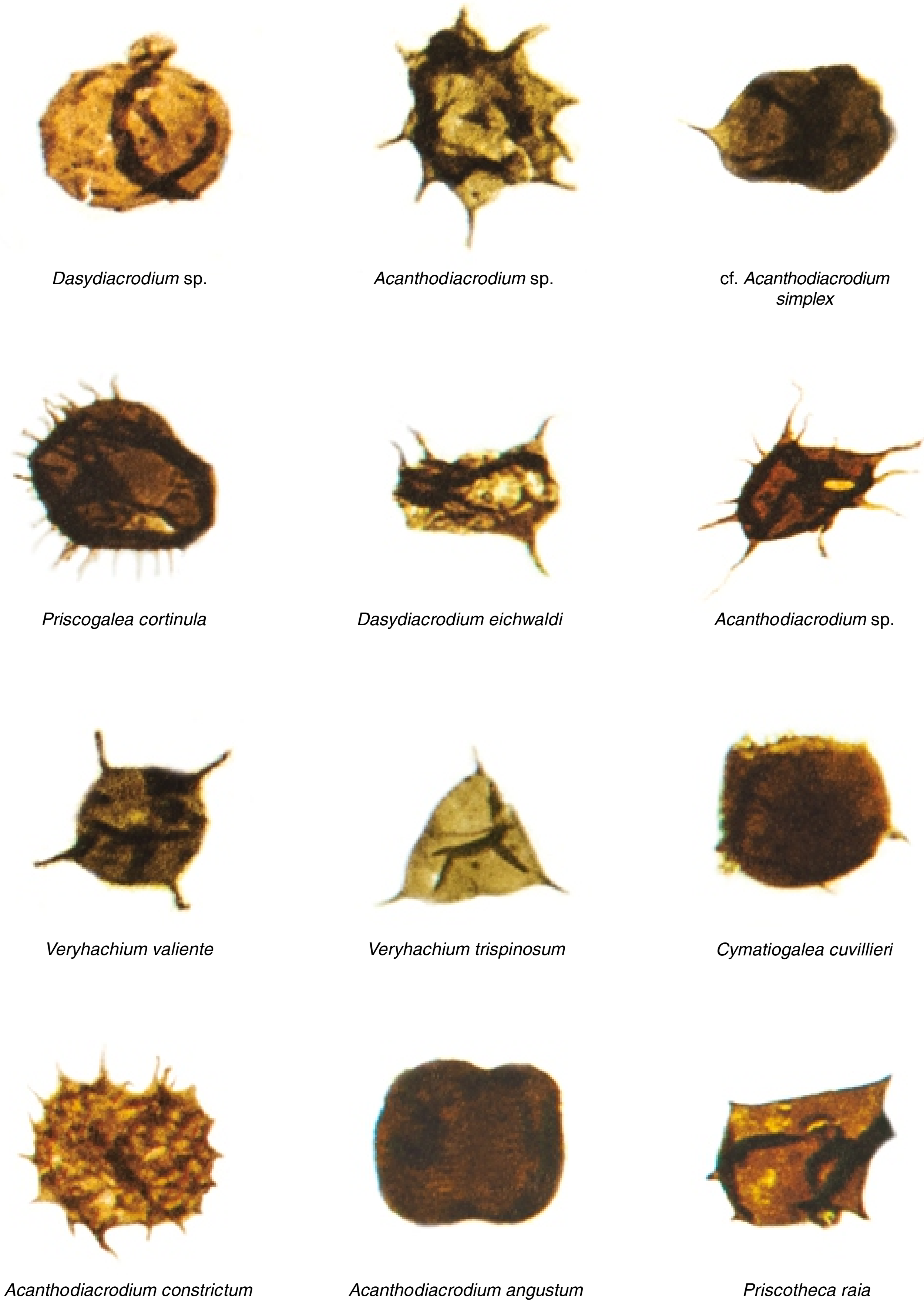

Figure 12. Ordovician acritarchs from the Araracuara section samples. Adapted from Théry et al. (1986). Photos without scale.

would have been very difficult to complete this manuscript. We would also like to thank geologist Fernando ALCÁRCEL GUTIÉRREZ, and photographer and graphic designer Alejandra CARDONA MAYORGA for their collaboration during the editing of the figures and tables.

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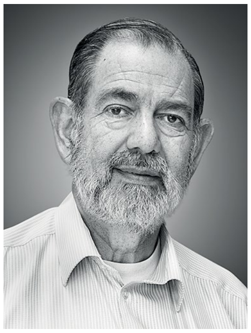
Explanation of Acronyms, Abbreviations, and Symbols:

BP	Before present	ft	Foot

Authors' Biographical Notes



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Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian

he worked remotely at Bioss S.A.S. as a support member in research pertaining to the regional geology of Colombia. Furthermore, he worked at ÍSOR (Icelandic Geo Survey) as an assistant geologist in the summer of 2010 and at the Icelandic Meteorological Institute (Veðurstofa Íslands) as a specialist in volcanology in 2011. Most recently, he has been pursuing a PhD degree at the Universidad Nacional de Colombia. Additionally, he has been involved in promoting ethics in geosciences as a member of the IAPG (International Association for Promoting Geoethics).