Boletín Geológico

Boletín Geológico, 47, 35-65, 2020
https://doi.org/10.32685/0120-1425/boletingeo.47.2020.494

Received: May 12, 2020
Revised: July 27, 2020
Accepted: September 17, 2020
Published online: December 28, 2020

Lithology and geochemistry of the Guadalupe Group base around Tunja, Boyacá, Colombia

Litología y geoquímica de la base del Grupo Guadalupe, en los alrededores de Tunja, Boyacá, Colombia

German **Martínez Aparicio**[1], Pedro **Patarroyo**[2] and Roberto **Terraza Melo**[1]

1. Servicio Geológico Colombiano, (SGC), Bogotá, Colombia.
2. Universidad Nacional de Colombia, (UNAL), Bogotá, Colombia.
Corresponding author: German Martínez Aparicio, gamartinez@sgc.gov.co

Abstract

The base of the Guadalupe Group, in the Tunja area of Colombia, contains cherts, porcellanites, mudstones, and siltstones with subordinate quartz arenites. The lithostratigraphic description of two stratigraphic sections showed that the dominant facies have fine granular textures and siliceous compositions, which considerably differ from those of the prevailing sandy terrigenous facies described in the type locality in the Eastern Hills of Bogotá, in the Arenisca Dura Formation, the basal unit of the Guadalupe Group in this sector.

The units that form the Guadalupe Group (base of the Guadalupe Group, Plaeners, and Arenisca Tierna) markedly differ from each other morphologically, which facilitates their mapping because the base and top units generate a steep morphology, and the intermediate units form surface depressions or valleys, similar to the morphology of the Guadalupe Group in its type locality in the Eastern Hills of Bogotá. The base of the Guadalupe Group consists of cherts and porcellanites toward the NW of the study area (Alto del Gavilán section), with mudstones, siltstones, quartz arenites, and to a lesser extent porcellanites and cherts prevailing toward the SE (Vereda Salitre section).

Geochemical analysis of total rock samples by XRD and XRF confirmed the primarily siliceous nature of the base of the Guadalupe Group, with SiO_2 ranging from 62 to 98%, CaO less than 3.0%, and P_2O_5 peaking at 15.0%. Etayo-Serna (2015) conducted paleontological determinations of ammonites found in the stratigraphic section of Alto del Gavilán and assigned the base of the Guadalupe Group mainly to the Lower Campanian.

Keywords: Guadalupe Group, lithology, porcellanites, cherts, Tunja.

Resumen

La base del Grupo Guadalupe, en los alrededores de Tunja, está representada por *cherts*, porcelanitas, lodolitas y limolitas con cuarzoarenitas subordinadas. A partir de la descripción litoestratigráfica realizada en dos secciones estratigráficas se estableció que

Citation: Martínez Aparicio, G., Patarroyo, P., & Terraza Melo, R. (2020). Lithology and geochemistry of the base of the Guadalupe Group, in the Tunja area, Boyacá, Colombia. *Boletín Geológico*, *47*, 35-65, https://doi.org/10.32685/0120-1425/boletingeo.47.2020.494

las facies dominantes son de textura finogranular con composición silícea, que difieren sustancialmente de las facies terrígenas arenosas predominantes, descritas en la localidad tipo en los cerros orientales de Bogotá, en la Formación Arenisca Dura, unidad basal del Grupo Guadalupe en ese sector.

Las unidades que integran el Grupo Guadalupe (base del Grupo Guadalupe, Plaeners y Arenisca Tierna) presentan contraste morfológico marcado entre ellas, que permite cartografiarlas fácilmente, ya que las unidades de base y techo generan una morfología escarpada y la intermedia depresiones o valles en la superficie, similar a la morfología que presenta el Grupo Guadalupe en su localidad tipo, en los cerros orientales de Bogotá. La base del Grupo Guadalupe hacia el NW del área de estudio (sección Alto del Gavilán) está compuesta por *cherts* y porcelanitas, y hacia el SE (sección vereda Salitre) predominan lodolitas, limolitas y cuarzoarenitas con menor proporción de porcelanitas y *cherts*.

Los análisis geoquímicos realizados en roca total (DRX y FRX) reafirman la naturaleza principalmente silícea de la base del Grupo Guadalupe, con porcentajes entre 62% al 98% de SiO_2, CaO menor al 3,0% y 15,0% máximo de P_2O_5. Etayo-Serna (2015) realizó determinaciones paleontológicas en amonitas encontradas en la sección estratigráfica del Alto del Gavilán, y asignó principalmente al Campaniano Inferior la base del Grupo Guadalupe.

Palabras clave: Grupo Guadalupe, litología, porcelanitas, *cherts*, Tunja.

1. Introduction

From 2012 to 2015, the *Servicio Geológico Colombiano* (SGC) conducted detailed prospecting of 1600 km^2 in the Tunja area, in the department of Boyacá, in a sector of Plate 191, Tunja (Renzoni et al., 1976); such prospecting (Terraza et al., 2016) made it possible to redraw the geologic map of this region of the Eastern Cordillera of Colombia into a new stratigraphic panorama of the Upper Cretaceous corresponding to the Guadalupe Group. This new geological knowledge is partly reported in this article.

The study area is located in the central region of the Eastern Andes (Eastern Cordillera) of Colombia, in the Tunja area, where two stratigraphic sections were measured that included the base of the Guadalupe Group: one in Alto del Gavilán in the municipality of Motavita, and the other in Vereda Salitre in the municipality of Soracá (see the location in the geological framework), where the lithostratigraphic and geochemical characteristics of this unit were described in detail.

1.1 Stratigraphic nomenclature of the Guadalupe Group

The term "Guadalupe" was introduced by Hettner (1892, pp. 1-351), referencing Upper Cretaceous rocks, present in the Eastern Andes of Colombia, or Bogotá mountain range, which he designated the *Guadalupe Stage* (Table 1).

To the east of Cundinamarca and the Bogotá savanna, Hubach (1931, pp. 126-150) divided the Guadalupe Stage into two sets: "an upper set of sandstone and a lower set of schist". The upper set, which is currently known as the Guadalupe Group, was subdivided into three horizons at the time: an upper horizon of soft sandstones, a middle horizon of Plaeners, and a lower horizon of hard sandstones.

Hubach (1951, pp. 10-13) assigned the *formation* rank to the Guadalupe Stage in the Bogotá savanna, dividing it into two sets: an upper set, consisting of sandstones and Plaeners, which is currently known as *Guadalupe Group*; and a lower schistose-clayey set with intercalating quartzitic sandstone horizons and strata, which is currently known as *Chipaque Formation*. He divided the upper set into three horizons: an upper horizon, which he termed *Arenisca Tierna* (*Soft sandstone*); a middle horizon, which he termed Plaeners and which included *Arenisca Labor*; and a lower horizon, designated *Arenisca Dura* (*hard sandstone*). In addition, based on the level of *Exogyra mermeti* and on the fauna of crushed ammonites next to bivalves found in the lower set of the Guaduas Formation, he stratigraphically ranked the Guadalupe Formation between the Coniacian and the Maastrichtian.

Hubach (1957, pp. 39-46) promoted the Guadalupe Formation to the *group* rank, subdividing it into a lower clayey formation, or Lower Guadalupe, and an upper sandy formation, or Upper Guadalupe. The Lower Guadalupe Formation, consisting of clayey and quartzitic sandy facies, currently belongs to the Chipaque Formation; the Upper Guadalupe can be subdivided into Areniscas Duras, Plaeners, and Arenisca Tierna. Hubach (1957, pp. 39-46) assigned to Upper Guadalupe a stratigraphic rank between the Turonian and the Lower Maastrichtian (Table 1).

Bürgl (1959, pp. 2-6) introduced a new stratigraphic nomenclature for the Guadalupe Group, which, from the top to the base, corresponded to "Arenisca Tierna, Plaeners Superiores [Upper Plaeners], Arenisca Dura, Plaeners and Clays, unnamed Sandstone, Plaeners and Sandstones, First Lidita, unnamed Sandstone, Plaeners and Sandstones, and Second Lidita". The Arenisca Dura of Bürgl (1959) corresponds to the Arenisca Labor of Hubach (1957). In the stratigraphic section of Chía-Tabio-Tenjo that Bürgl illustrated (1959, pp. 2-3), Arenisca Tierna represents the Middle Maastrichtian; Arenisca Dura (or Arenisca Labor according to Hubach), the Lower Maastrichtian, characterized by the presence of "*Nostoceras*, *Ostrea tecticosta* and *Siphogenerinoides bramlettei*" (Bürgl, 1959, pp. 2-6); and the First Lidita represents the Lower Campanian.

Pratt et al. (1961) redefined the Guadalupe Group, restricting it to the *Upper Guadalupe or Upper Sandy Set* and dividing it from the base to the top as follows: "Arenisca Raizal, Lower Plaeners, Arenisca Dura, Upper Plaeners and Arenisca Tierna". For these authors, Lower Plaeners contained the First Lidita of Bürgl, and Arenisca Dura corresponded to the Arenisca Labor of Hubach.

Renzoni (1962), based on a purely lithostratigraphic criterion, divided the Guadalupe Group into practical and mappable units easily recognizable in the field. For this reason, he decided to combine Arenisca Labor (which Hubach [1951, pp. 10-13] included in the top of the Plaeners horizon) with Arenisca Tierna into a single sandy lithostratigraphic unit termed the Arenisca Labor-Tierna Formation. Thus, the Guadalupe Group was formed, from the base to the top, by the Arenisca Dura Formation, the Plaeners Formation, and the Arenisca Labor-Tierna Formation.

Etayo-Serna (1964) assigned a Santonian-Campanian rank to the base of the Guadalupe Group (east of the Bogotá savanna), exclusively considering the stratigraphic position of the Raizal Member. Among the typical fauna of the base of the Raizal Member, Etayo-Serna mentioned *Ostrea nicaisei*, which had been described by Hubach (1957, pp. 39-46). Furthermore, Etayo-Serna assigned the Plaeners Level, which overlies the Raizal Member, to the Lower Maastrichtian, based on the following fauna: *Siphogenerinoides clarki* Karsten, *Ostrea tecticosta* Gabb, *Ostrea falcata* Morton, *Siphogenerinoides clarki* Cushman & Campbell, and *Sphenodiscus*, among others.

In the Tunja area, Renzoni (1981) and Renzoni et al. (1976) divided the Guadalupe Group into the Plaeners Formation (kg2) and the Arenisca Labor-Tierna Formation (kg1) and indicated that the Arenisca Dura Formation (kg3) of the Bogotá savanna might correspond to some sandstones found in the top of the Conejo Formation of this locality (Table 1). They described the following fauna: *Baculites* sp. in the Plaeners Formation, *Ostrea abrupta* in the Labor-Tierna Formation, and *Lenticeras baltai* in the top of the Conejo Formation, the last of which is from the Santonian, according to Etayo-Serna (1968b, 1969).

Pérez and Salazar (1978) described in detail the formations that compose the Guadalupe Group, located east of Bogotá (Guadalupe hill and Rajadero páramo), thereby formally defining its units, which from the base to the top are the Arenisca Dura Formation, the Plaeners Formation, the Arenisca Labor Formation, and the Arenisca Tierna Formation (Table 1). Arenisca Dura would range from the Coniacian or Santonian to the Campanian, considering the age of the overlying Plaeners Formation, which these authors assigned to the Lower Maastrichtian based on the observed *Ostrea tecticosta* Gabb, *Orthocarstenia cretacea* (Cushman), *Orthocarstenia clarki* (Cushman and Campbell), and *Globigerinacea*.

Föllmi et al. (1992), in a section in Tausa (Cundinamarca), collected fossil fauna from the Lower Plaeners Member, overlying the Raizal Member (=A. Dura) of the Guadalupe Formation. According to the authors, these fossils included *Nostoceras* (*Nostoceras) liratum*, *Exiteloceras jenneyi*, *Libycoceras* sp., and remains of the dinoflagellate *Andalusiella polymorpha*, dated between the Upper Campanian and the Lower Maastrichtian (Table 1).

In the Llanero foothills (municipality of San Luis de Gaceno), in a section measured in the San Antonio ravine, Guerrero and Sarmiento (1996) divided the Guadalupe Group, from the base to the top, as follows: Lower Guadalupe (Arenitas de San Antonio Formation), Middle Guadalupe (Lodolitas de Agua Caliente Formation), and Upper Guadalupe (Arenitas de San Luis de Gaceno Formation). Based on palynological analyses, they assigned the following stratigraphic ranks to these units: Lower Campanian to Lower Guadalupe, Upper Campanian to Middle Guadalupe and Lower Maastrichtian to Upper Guadalupe.

More recently, in geologic mapping studies of the SGC, Montoya and Reyes (2003 a, b; 2005 a, b; 2007), in the Bogotá savanna and Plate 209, Zipaquirá, Colombia, identified the Upper Lidita Formation (nomenclature of the Upper Magdalena Valley (Valle Superior del Magdalena)) at the base of the Guadalupe Group, a unit considered contemporary to and heteropic with the Arenisca Dura Formation of the Bogotá savanna (Table 1). Montoya and Reyes (2003 a, b) assigned the Upper Lidita Formation to the Lower Campanian, based on the fossil fauna found in the top of the Conejo Formation (municipality of Ubaté), corresponding to "*Texanites (Texanites)* cf. *quinquenodosus* (Redtenbacher) cf. Kennedy et al. (1981); *Glyptoxoceras* sp. cf. *crispatum* (Moberg), cf. Kennedy et al. (1995); *Eulophoceras* sp. indet., cf. Kennedy et al. (1995), and *Baculites* sp. Indet".

Similarly, Terraza et al. (2010), in Plate 210, Guateque, Colombia (NW sector, grid 210: A1), and Terraza et al. (2016), in phosphate exploration in the Tunja area, mapped the Upper Lidita Formation at the base of the Guadalupe Group.

In this article, the informal nomenclature proposed by Martínez (2018) for the area located between Ventaquemada and Toca ("base of the Guadalupe Group") (Table 1) will be used while the SGC decides whether to accept the nomenclature of Montoya and Reyes (2003 a, b; 2005 a, b; 2007).

2. Geological framework

Cretaceous sedimentary rocks of the Conejo Formation and Guadalupe Group crop out in the study area. They are overlaid by the Guaduas, Cacho, and Bogotá formations of the Paleogene. In some sectors, these units are discordantly covered by Neogene and Quaternary deposits. Structurally, the area is influenced by the Combita Syncline, Tunja Syncline, and Puente Hamaca Anticline as well as the Chivatá and Puente Hamaca thrust faults, which place the Upper Cretaceous rocks in contact with the Paleogene rocks (Figure 1). Morphologically, in the Tunja area, as in the Bogotá savanna, the base of the Guadalupe Group and the Arenisca Tierna Formation generate an escarpment, whereas the Plaeners Formation originates a valley.

Conejo Formation. The Conejo Formation crops out toward the northwest of Motavita and the southeast of Soracá, forming belts with a SW-NE direction (Figure 1). The upper part of the unit forms a valley and is clearly distinguishable from the base of the Guadalupe Group, which generates a ridge. Lithologically, the lower section contains thick bundles of mudstones with dark claystones; the middle section shows quartz arenites interspersed with claystones and siliceous siltstones; the upper section reveals claystones and mudstones with frequent intercalations of quartz arenites and sporadic layers of bivalve wackestone, with layers of siliceous siltstones.

Base of the Guadalupe Group. The Base of the Guadalupe Group forms belts oriented in the SW-NE direction, which are part of the flanks of the Tunja Syncline, Cómbita Syncline, and other, minor folds (Figure 1). It is characterized by a succession of porcellanites, fossiliferous cherts with wackestone textures of foraminifera and bioclasts, mudstones, quartz arenites, siltstones, and some silicified phosphatic layers that have benthic foraminifera and bioclasts. It lies concordantly

Table 1. Stratigraphic Nomenclature for the Upper Cretaceous in the central region of the Eastern Andes of Colombia

<table>
<tr><th>Bogotá Savanna
Hettner (1982)</th><th colspan="2">Bogotá Savanna
Hubach (1957)</th><th>Bogotá Savanna
Bürgl (1959, 1960)</th><th colspan="2">Villa de Leyva
Etayo-Serna (1968)</th><th colspan="2">J-12 Tunja
Renzoni (1981)</th><th>Bogotá Savanna
Pérez and Salazar
(1978)</th><th colspan="2">Tausa
Föllmi et al. (1992)</th><th>Pl-209 Zipaquirá
Montoya and Reyes
(2003a, 2005a)</th><th colspan="2">Pl-191 Tunja
The present study
(2020)</th></tr>
<tr><th>Guaduas Stage</th><th colspan="2">Guaduas Formation</th><th>Guaduas Formation</th><th colspan="2">Guaduas Formation</th><th colspan="2">Guaduas Formation</th><th>Guaduas Formation</th><th colspan="2">Guaduas Formation</th><th>Guaduas Formation</th><th colspan="2">Guaduas Formation</th></tr>
<tr><td rowspan="7">Guadalupe Stage</td><td rowspan="4">Upper Guadalupe Formation</td><td>Arenisca Tierna</td><td>Arenisca Tierna</td><td rowspan="3">Unknown formations</td><td>Arenisca Tierna</td><td colspan="2" rowspan="3">Labor and Tierna Formation
Kg1</td><td>Arenisca Tierna Formation</td><td rowspan="4">Guadalupe Formation
Lower Plaeners</td><td rowspan="2">Tierna
Upper
Plaeners</td><td rowspan="2">Labor-Tierna Formation</td><td rowspan="4">Guadalupe Group</td><td rowspan="2">Arenisca Tierna Formation</td></tr>
<tr><td rowspan="2">Arenisca Labor-Plaeners</td><td>Upper Plaeners
Arenisca Dura</td><td rowspan="2">Clayey siltstone Set</td><td>Arenisca Labor Formation</td></tr>
<tr><td>Plaeners and Arcillas unnamed sandstone</td><td>Plaeners Formation</td><td>Labor</td><td>Plaeners Formation</td><td>Plaeners Formation</td></tr>
<tr><td>Arenisca Dura</td><td>Plaeners and Areniscas
First Lidita</td><td colspan="2">Plaeners Formation</td><td colspan="2">Plaeners Formation
Kg2</td><td>Arenisca Dura Formation</td><td>Raizal = Dura
Upper Chert</td><td>Arenisca Dura/
Lidita Superior</td><td>Base of the Guadalupe Group</td></tr>
<tr><td colspan="2" rowspan="3">Lower Guadalupe Formation</td><td>Unnamed sandstone</td><td rowspan="3">Conejo Formation</td><td>Segment C</td><td rowspan="3">Conejo Formation</td><td>Kg3 (same as Arenisca Dura)</td><td rowspan="3">Villeta Group</td><td colspan="2" rowspan="3">Villeta Formation</td><td rowspan="3">Conejo Formation</td><td colspan="2" rowspan="3">Conejo Formation</td></tr>
<tr><td>Plaeners and Areniscas</td><td rowspan="2">Segment B
(Cucaita Member)</td><td rowspan="2"></td></tr>
<tr><td>Second Lidita</td></tr>
</table>

over the Conejo Formation, in rapid transitional contact. The upper contact with the Plaeners Formation is abruptly concordant with mudstones, claystones, and some porcellanites and with abundant benthic foraminifera.

Plaeners Formation. Similarly, to the base of the Guadalupe Group, this unit crops out, forming belts oriented in the SW-NE direction, which are part of the flanks of the Tunja Syncline, San Francisco Anticline, Cómbita Syncline, and other, minor folds (Figure 1). It is identified by its clayey character, with mudstones, some porcellanites, siltstones, quartz arenites, and some phosphatic layers. It lies concordantly over the base of the Guadalupe Group and underlies the Arenisca Tierna Formation.

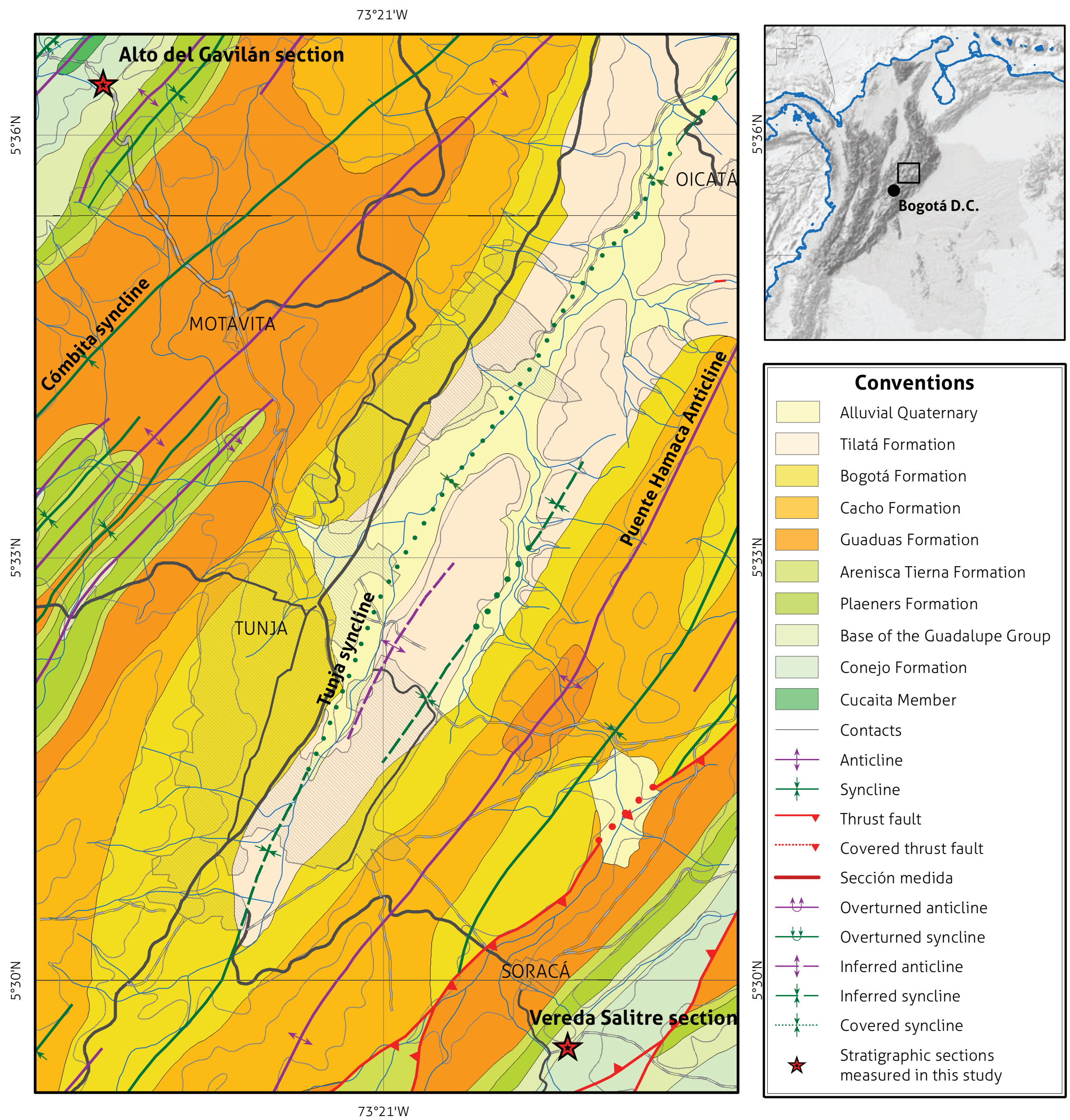

Figure 1. Geology of the study area and location of the stratigraphic sections measured in this study
Source: geologic base map retrieved from Terraza et al. (2016)

3. Method

Initially, the two stratigraphic sections in the study area were located and georeferenced using a GPS. Later, a measurement was performed at 1:100 scale using a Jacob's staff and a Brunton compass. We recorded the primary data in the format adapted by the SGC in 2013.

The following proposals were used to describe the stratigraphic sections: layer and lamina thickness according to Campbell (1967); geometric description of layers and laminae according to Reineck and Singh (1980), degree of progressive destruction of lamination by bioturbation according to Moore and Scrutton (1957); rock color according to the Munsell color system of the Geological Society of America (1991); degree of rock weathering according to the terminology of the Geological Society of London (1990); grain-shape and particle-size comparison diagram according to Krumbein and Sloss (1969); particle selection type and descriptive terminology according to Pettijohn, Potter, and Siever (1973); types of contacts between grains according to Taylor (1950); state of textural maturity of siliciclastic rocks according to Folk (1954); percentages of fossils and other allochems according to the charts of Baccelle and Bosellini (1965); textural classification of siliciclastic sedimentary rocks according to Folk (1954); compositional classification according to Folk (1974); and textural classification of calcareous rocks according to Dunham (1962) and Folk (1962).

Siliceous rocks were classified, both texturally and compositionally, according to Williams et al. (1954) and to Lazar et al. (2015), considering the percentage of microcrystalline quartz of the rock, as follows: The rock was classified as chert when the values ranged from 80% to 100%; as porcellanite, from 50% to 80%; and as mudstone or siliceous claystone, from 25% to 50%.

Both stratigraphic sections were systematically sampled for petrographic and geochemical analysis. The samples were sent to the Chemical Laboratory of the SGC, where they were analyzed by X-ray diffraction (XRD) and X-ray fluorescence (XRF) according to the protocols and methods established by the SGC.

The paleontological material collected in the two stratigraphic sections was analyzed by Dr. Etayo-Serna.

4. Results

The results reported in the present article correspond to the detailed lithostratigraphic description of the base of the Guadalupe Group and to XRD and XRF data of the samples collected in the two stratigraphic sections measured in this study.

4.1 Lithostratigraphic Description

This description was performed based on two stratigraphic sections measured by Martínez (2018). The first section is located on the road that connects the municipalities of Soracá and Boyacá (Boyacá), in Vereda Salitre (Figures 1 and 2), and includes the base of the Guadalupe Group and part of the Plaeners Formation. The second section, in Alto del Gavilán, along the road from Motavita to the Honda stream sector (Figures 1 and 17), includes the upper part of the Conejo Formation and the base of the Guadalupe Group.

4.1.1 Stratigraphic section of Vereda Salitre

The measured thickness was 275 m. The coordinates of the starting point are N: 1099136; E: 1083027; Z: 2858 m a.s.l. The coordinates of the end point are N: 1099257; E: 1082621; Z: 2804 m a.s.l. The outcrop has an average N41°E strike and 51° NW dip (Figure 2).

The section was divided into five segments (Figure 3), termed, from the base to the top, A, B, C, D, and E. Segments A, B, and C have a thickness of 99.8 m and correspond to the base of the Guadalupe Group; segments D and E have a thickness of 171.4 m and are part of the Plaeners Formation. The contact with the Conejo and Plaeners formations is covered (Figure 4).

In general, in this stratigraphic section, the base of the Guadalupe Group is characterized by the presence of porcellanites and cherts with a wackestone texture toward the base and a portion of the top. In contrast, mudstones, siltstones, claystones, and sporadic layers of very fine-grained quartz arenites prevail in the middle and higher parts.

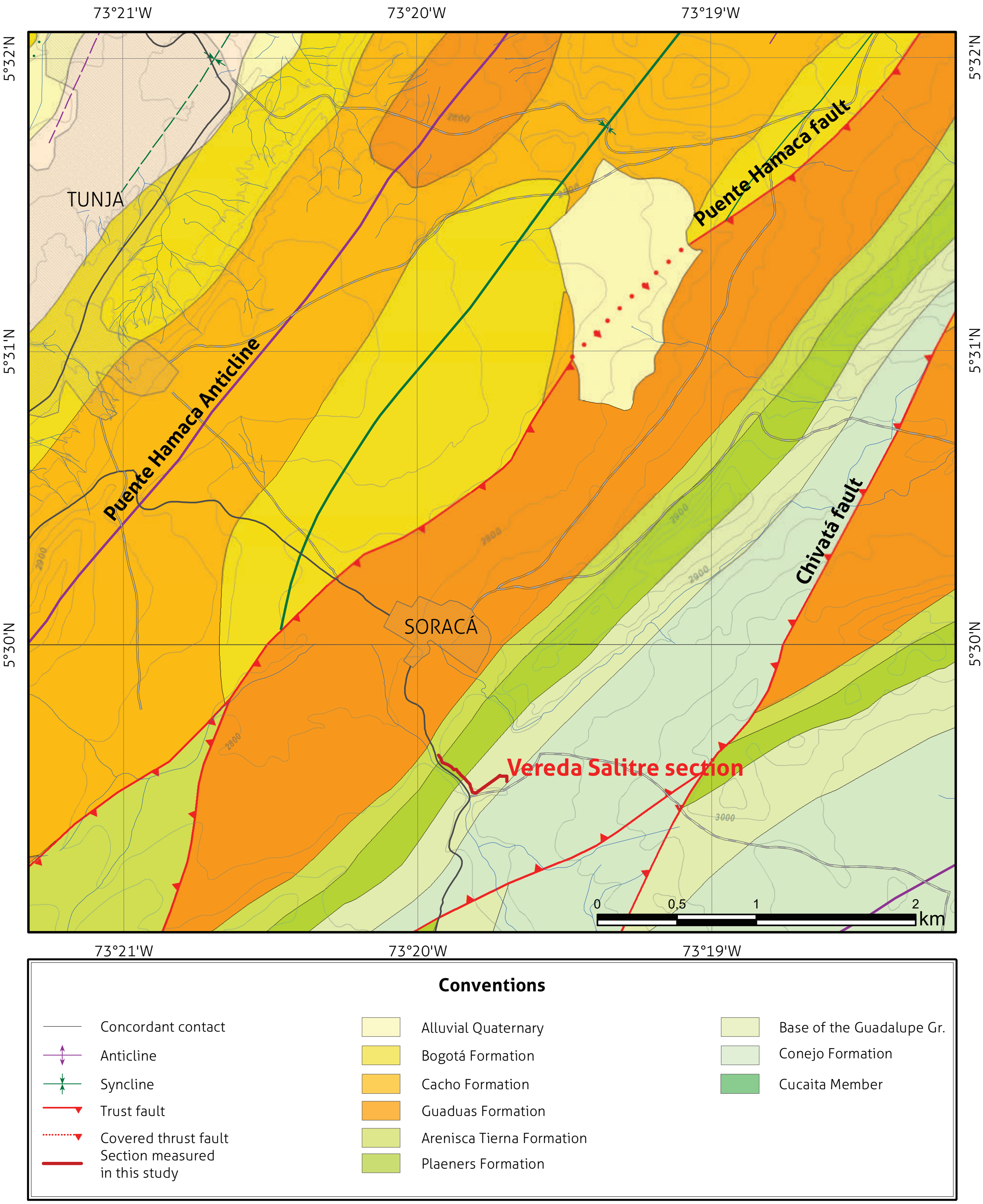

Figure 2. Location and local geology of the Vereda Salitre stratigraphic section
Source: geologic base map retrieved from Terraza et al. (2016)

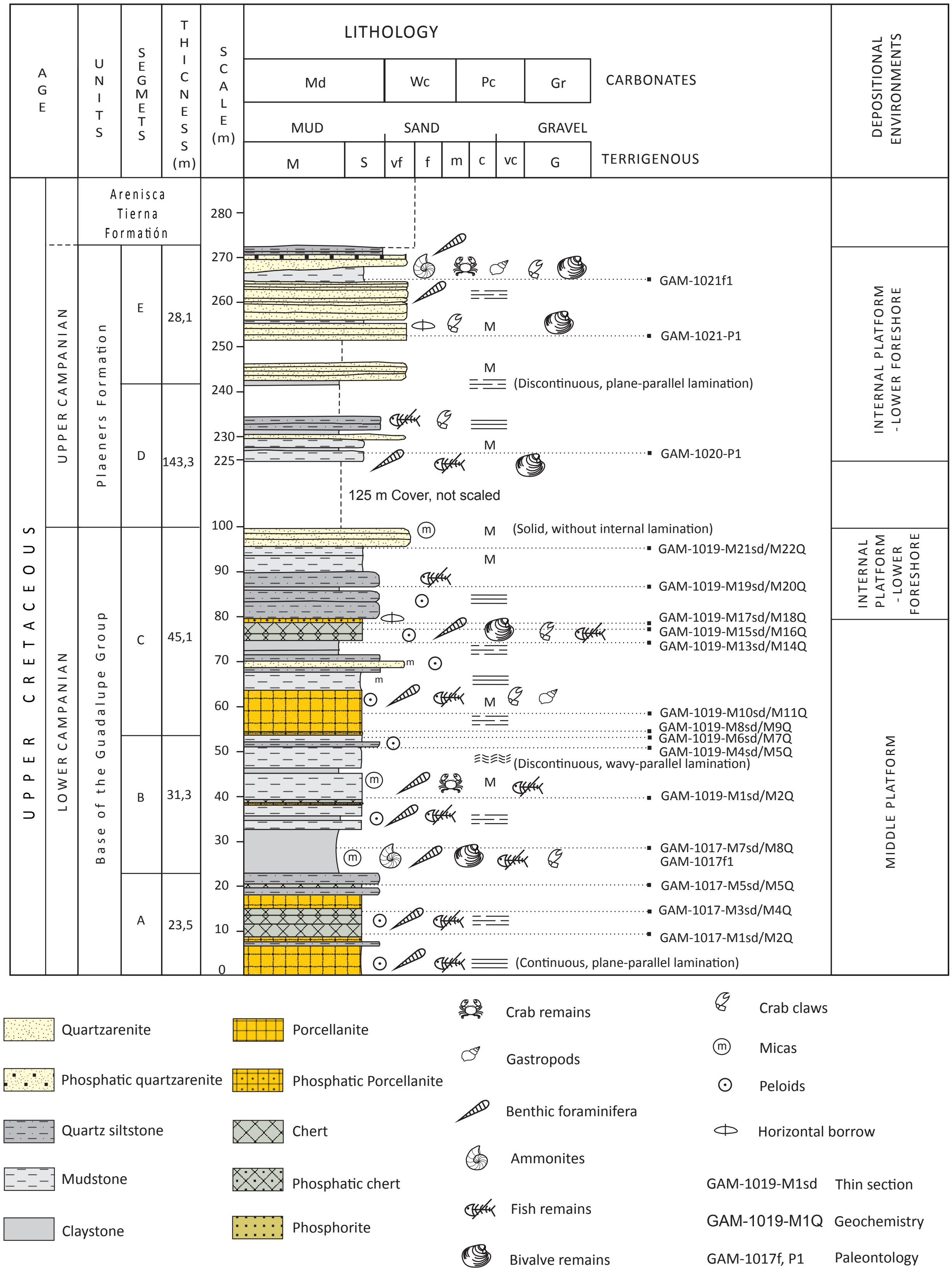

Figure 3. Stratigraphic section of Vereda Salitre

4.1.2 Base of the Guadalupe Group

Segment A (0.0-23.5 m). Segment A was measured in the quarry located by the road from Soracá to the municipality of Boyacá (Figure 5). The layers show continuous, plane-parallel bedding and very thin, discontinuous, plane-parallel lamination. The low part shows 18.5 m of very thin to thin layers of chert with foraminifera and bioclast wackestone texture (Figure 6) and light-gray and orange-grayish-pink porcellanites, with sporadic thin layers of yellowish-gray mature quartz siltstones, without internal lamination. The high part of segment A shows 5 m of thin, medium, and thick layers of bluish-white siltstones and some layers of chert. This interval contains benthic foraminifera, fish remains, and peloids, in addition to some very slightly phosphatic layers. Rocks are moderately weathered with low bioturbation.

Segment B (23.5-53.0 m). Segment B was partly measured in the quarry and partly in the road from Soracá to the municipality of Boyacá (Figures 5 and 9). The layers present continuous plane-parallel bedding and mostly very thin, discontinuous, plane-parallel lamination. From the base to the top, 9.7 m of thick to very thick layers of bluish-white claystones are observed (Figure 7), followed by 4.6 m of medium to thick layers of pale-greenish-yellow mudstones with low bioturbation and sporadic medium, laminated layers of light-brownish-gray claystones. Ascending stratigraphically, a thin, laminated layer of phosphatic porcellanite is found, followed by thin layers of light-brownish-gray chert, with nonvisible lamination and prismatic partitioning. They are followed by 11.6 m of thin to very thin layers of light-brownish-to-brownish gray mudstones, with sporadic layers of siltstones. Segment B ends in a section with 3.2 m of thin to medium, tabular layers of brownish-gray mudstones, with very thin, discontinuous, plane-parallel, lenticular heterolithic lamination and low bioturbation (Figure 8) and medium to thick, tabular layers of yellowish-gray siltstones. This interval contains benthic foraminifera laminae, fish and crab remains, some bivalves, and ammonites, including Campanian "*Didymoceras stevensoni*? (Whitfield, 1877), *Hoploscaphites* sp. Inc.? and *Sphenodiscus* sp.?" (Etayo-Serna, 2015), as well as peloids, siliceous nodules, and muscovite as an accessory mineral.

Figure 4. Morphological contrast of the units of the Guadalupe Group and Conejo Formation in Vereda Salitre (N: 1099147; E: 1083034; Z: 2904; azimuth: 200°)

Figure 5. Abandoned quarry located by the Soracá-Boyacá road, showing segment A and part of segment B (N: 1099175; E: 1082984; Z: 2904; azimuth: 120°)

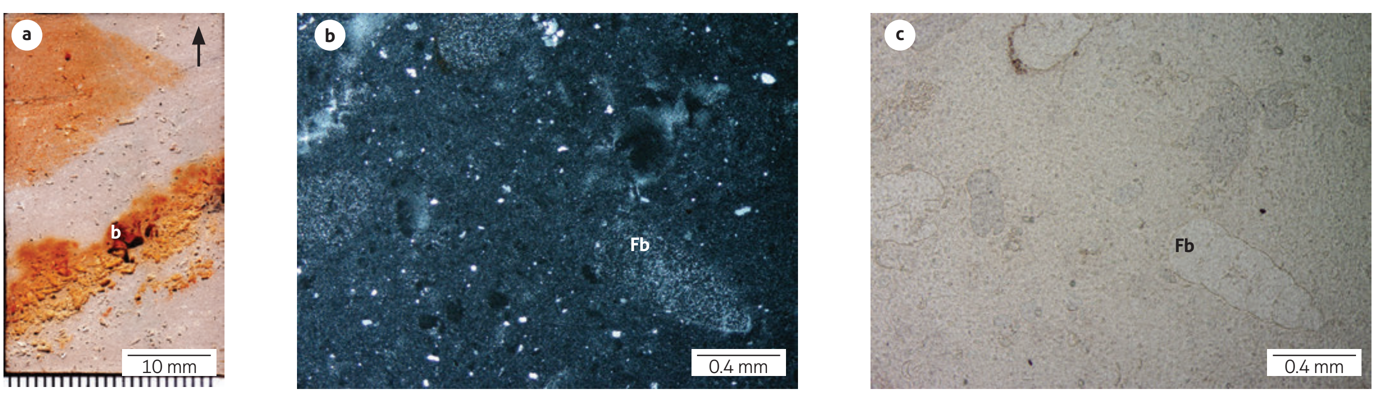

Figure 6. Polished section (a) and micrographs (b, c) of a chert with wackestone texture showing benthic foraminifera (Fb) and bioclasts (b) embedded in micro-crystalline quartz
Segment A, sample GAM-1017-M3sd, 14.7 m. Crossed (b) and parallel nicols (c).

Fb

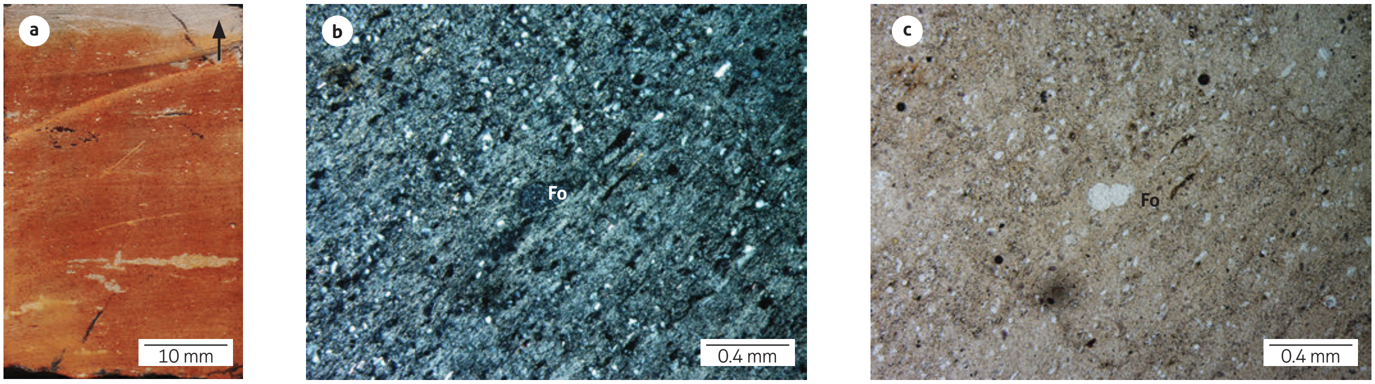

Figure 7. Polished section (a) and micrographs (b, c) of a claystone showing foraminifera (Fo) in a clay mineral framework
Segment B, sample GAM-1017-M7sd, 28.4 m. Crossed (b) and parallel nicols (c).

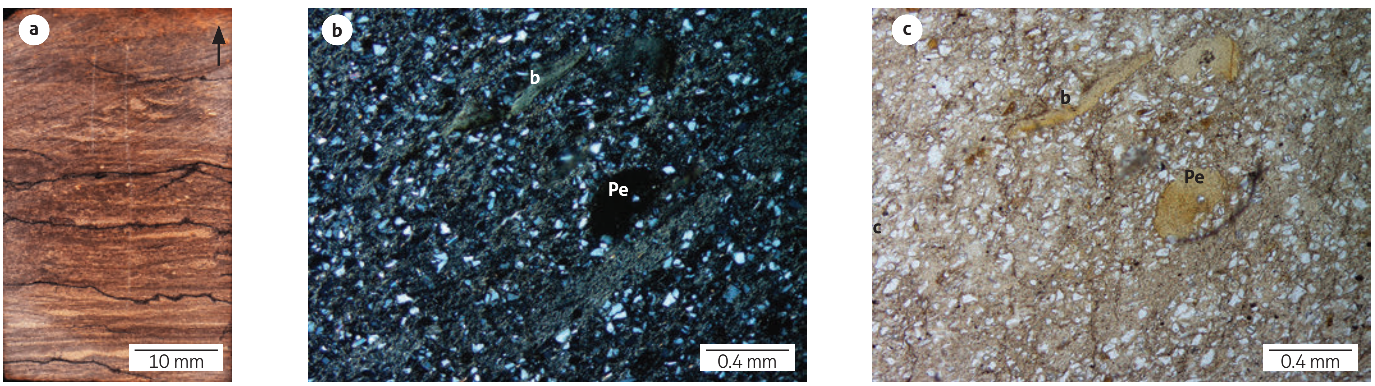

Figure 8. Segment C, sample GAM-1019-M4sd, 51.6 m
(a) Polished section of a mudstone with lenticular heterolithic lamination. B and C show bioclasts (b) and phosphatized peloids (Pe) supported by laminae of clay minerals and quartz grains. Micrograph of crossed (b) and parallel nicols (c).

Segment C (54.7-99.8 m). Segment C was measured in the road from Soracá to the municipality of Boyacá (Figure 9). Most layers show continuous plane-parallel bedding and very thin to thin, discontinuous, plane-parallel lamination. The lower, middle, and upper parts of the segment are described below.

The lower part begins with a 0.3 m layer of phosphatic porcellanite with peloids, followed by 8.7 m of a very thick set of layers, consisting of thin, medium, and thick layers of porcellanites and siltstones without internal lamination (Figure 10); bioturbation ranging from low to high; and sporadic medium layers of phosphatic porcellanites. Ascending stratigraphically, 3.5 m of thin layers of mudstones are found with low bioturbation, followed by 2.9 m of very thin to thin layers of siltstones, with low bioturbation, and then by 4.4 m of thin to medium layers of very fine-grained, somewhat phosphatic, mature quartz arenites, with moderate bioturbation, interspersed with thin to medium, tabular layers of siltstones and some mudstones. This interval is characterized by the presence of benthic foraminifera, fish remains, crab claws, gastropods, peloids, and muscovite as an accessory mineral; the typical colors are very light gray, light medium gray, light brownish gray, and pale greenish yellow.

The middle part of the segment (Figure 11) starts with 4.1 m of very thin, thin, and medium layers of cherts, with low bioturbation, interspersed with tabular, thin, and medium layers of porcellanites, followed by a tabular, (0.3 m) thin layer of phosphatic porcellanite (Figure 12), with peloids and bioclasts, high bioturbation, and horizontal burrows toward the base of the layer. Then we find a 10.6-m-thick section starting with very thin to thin layers of siltstones, low bioturbation, and sporadic layers of chert. This is followed by a tabular, medium layer of very fine-grained, mature quartz arenites, with bioturbation ranging from high to moderate. This layer continues to thin layers of porcellanites with nonvisible lamination, followed by thin to medium layers of siltstones with nonvisible lamination and high bioturbation and, finally, sporadic, thin to medium layers of claystones, porcellanites, and phosphatic mudstones. The typical colors are very light gray, medium gray, greenish yellow, and very pale orange.

The upper part of the segment shows 5.5 m of medium layers of mudstones, with high bioturbation and an interspersed, tabular, medium layer of claystones, followed by thin to medium layers of siltstones with high bioturbation and some layers of mudstones, ending with 3.3 m of tabular, thin to medium layers of very fine-grained quartz arenites with nonvisible lamination and high bioturbation. The rocks of this interval are brownish and yellowish gray. They contain remains of fish, crabs, peloids, crab claws, horizontal burrows, benthic foraminifera, and some bivalves in porcellanites, in addition to mica as an accessory mineral.

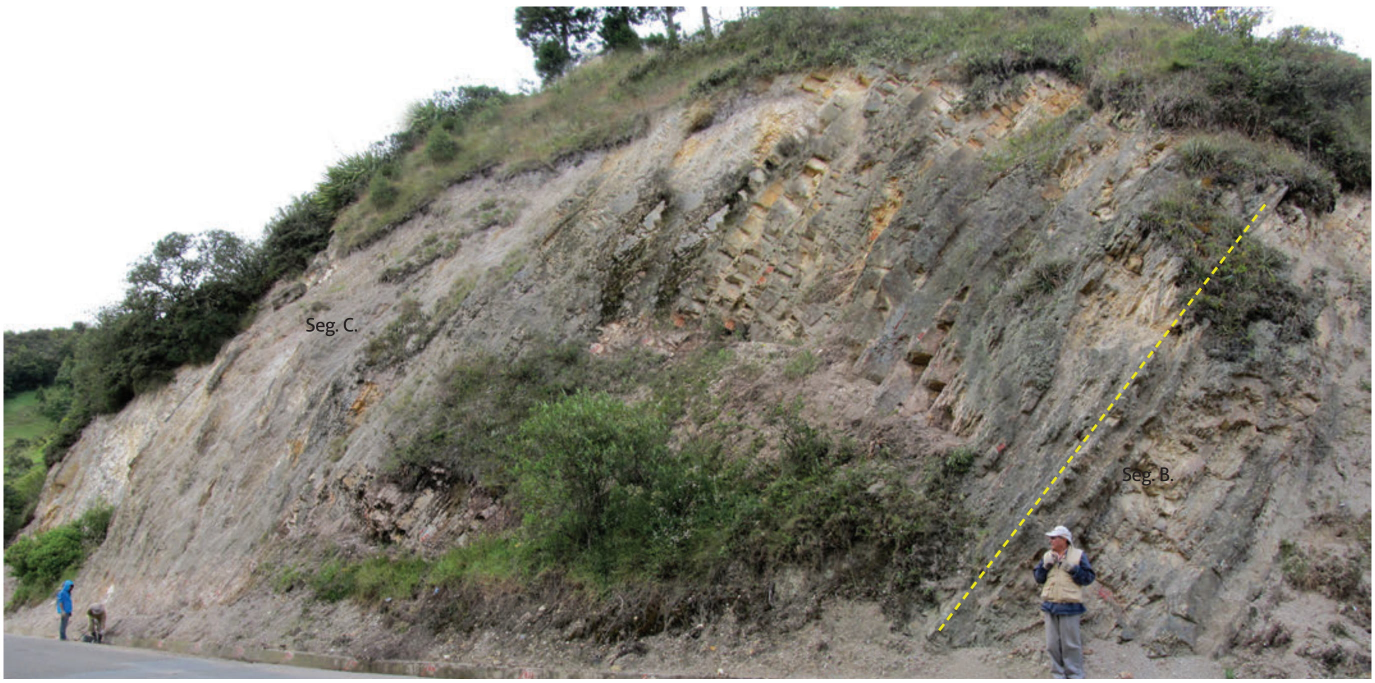

Figure 9. Outcrop in the Soracá-to-Boyacá roadcut showing segment C and the upper part of segment B. (N: 1099067; E: 1082810; Z: 2872; azimuth: 300°)

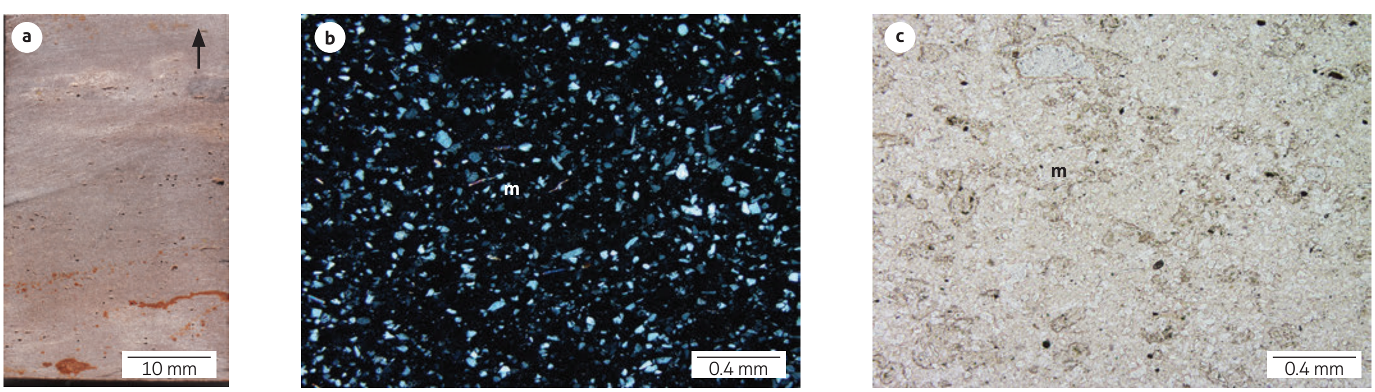

Figure 10. Polished section (a) of porcellanite. The micrographs show grains of muscovite (m) and quartz supported by microcrystalline quartz. Crossed (b) and parallel nicols (c). Segment C, sample GAM-1019-M10sd, 58.4 m.

Figure 11. Contact between the base of the Guadalupe Group, middle and upper part of segment C and the Plaeners Formation, which starts with a cover in segment D (N: 1099115; E: 10827950; Z: 2702; azimuth: 50°).

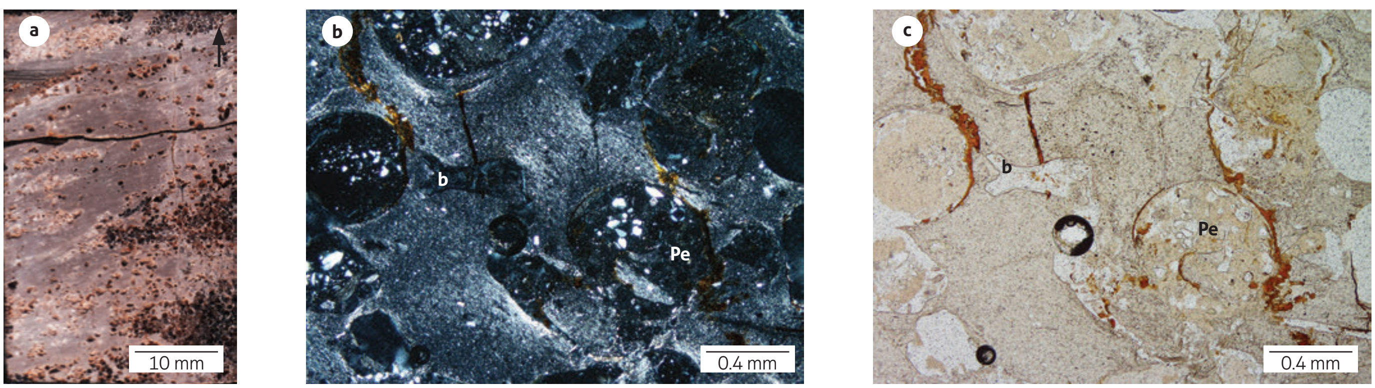

Figure 12. Polished section of a phosphatic porcellanite with wackestone texture
The micrographs show phosphatic peloids (Pe) and bioclasts (b) embedded in microcrystalline quartz. Crossed (b) and parallel nicols (c). Segment C, sample GAM-1019-M17sd, 79.6 m.

4.1.3 Plaeners Formation

Segment D (99.8-243.1 m). Most layers show continuous, plane-parallel bedding and thin to very thin, discontinuous, plane-parallel lamination. Segment D starts with a 125.1-m cover (Figure 13), followed by a 9.9-m-thick stratum consisting of thick and very thick layers of mudstones, with high bioturbation. Next, a tabular, medium layer of siltstones is followed by thick to very thick layers of mudstones; thick layers of claystones; thin to very thin layers of mudstones; a tabular, very thick layer of very fine-grained, mature quartz arenites; a tabular, very thick layer of claystone, with nonvisible lamination; a tabular, very thick layer of mudstone; and, lastly, medium to thick layers of siltstones. Ascending stratigraphically, a 7.3-m cover is then identified in this segment, which ends with 1 m of claystones in thin to medium layers. The rocks of this interval are medium gray, brownish gray, dark gray, and light olive gray and contain benthic foraminifera, fish remains, crab claws, some bivalves, peloids, and micas.

Segment E (243.1-271.2 m). The layers show continuous and discontinuous plane-parallel bedding, starting with 4.1 m of medium to thick layers of very fine-grained, mature quartz arenites with nonvisible lamination and high bioturbation, continuing with a cover of 5.1 m. Ascending stratigraphically, a 12.2-m-thick stratum starts with tabular, medium to thick layers of very fine-grained quartz arenites with discontinuous, nonparallel wavy lamination and medium bioturbation, followed by a very thick cuneiform layer of very fine-grained, mature quartz arenites with horizontal burrows toward the base with high bioturbation and large bivalves (>5 cm) of the Campanian species *Abruptolopha abrupta* (D'Orbigny, 1842) and *Gastrochaenolites socialis* (D'Orbigny, 1842) (Etayo-Serna, 2015), as shown in Figure 14. Next we find medium, thick, and very thick layers of very fine-grained, mature quartz arenites, with medium to high bioturbation and sporadic layers of siltstones. The rocks in this interval are grayish orange, very pale orange, and greenish yellow and contain peloids, crab claws, benthic foraminifera, and muscovite as an accessory mineral.

Higher up stratigraphically, we find 2.6 m of thick to very thick layers of grayish-orange mudstones with discontinuous plane-parallel bedding, high bioturbation, and the following ammonites (Figure 15):

> *Exiteloceras jenneyi jenneyi* (Whitfield, 1880), *Libycoceras* sp. inc. and *Sphenodiscus* sp. Inc.? and the bivalves *Gyrostrea* cf. *glabra* (Meek and Hayden, 1857), *Ostrea cretacea*? (Meek and Hayden, 1857), *Ostrea tecticosta* (Gabb, 1860), *Paranomia scabra* (Morton, 1834), *Tenuipteria* cf. *argenta* (Conrad, 1858), *Lima* cf. *acutilineata* (Conrad, 1858), and crab remains of the Upper Campanian (Etayo-Serna, 2015).

Segment E ends with a 5.2-m-thick stratum formed by medium to thick cuneiform layers of very fine-grained, pale-greenish-yellow quartz arenites with high bioturbation, followed by a thick, cuneiform layer of phosphatic, light-brown quartz arenites with peloids, then very thick layers of sandy, white siltstone with discontinuous, plane-parallel, thin lamination with bivalves and peloids, then a tabular, medium layer of porcellanite, and lastly medium to thick layers of silicious siltstones (Figure 16) with nonvisible lamination and with some benthic foraminifera and micas.

Figure 13. Contact between the base of the Guadalupe Group and the Plaeners Formation
Segment E is covered and shows soft morphology, typical of silt-clayey lithology (N: 1099140; E: 1 082775; Z: 2864; azimuth: 10°)

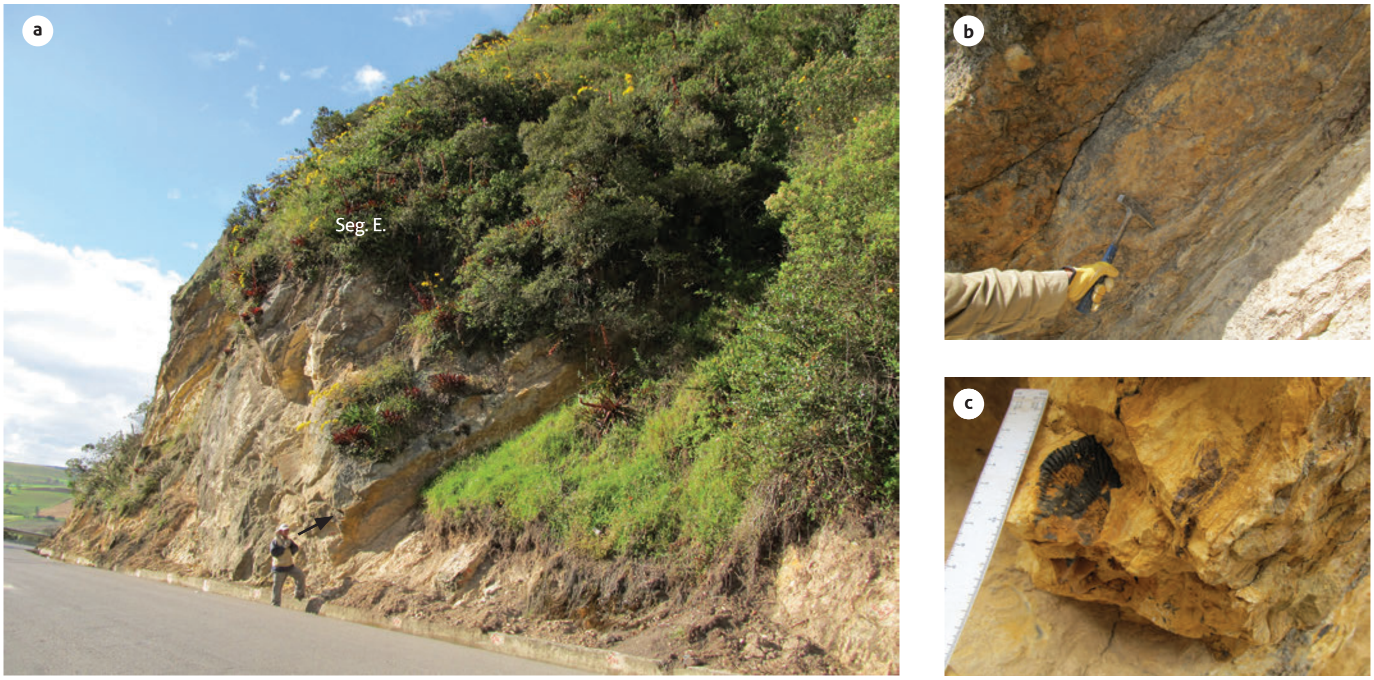

Figure 14. View of segment E of the Plaeners Formation (a)
The first layer of quartz arenites (black arrow) shows horizontal burrows toward the base (b) and *Abruptolopha abrupta* bivalves (c) (E: 1099231, N: 1082625; Z: 2884; azimuth: 30°).

Figure 15. Level of mudstones in segment E; some of the ammonites found in this segment are detailed on the right (N: 1099257; E: 1082621; Z: 2807)

Figure 16. Upper part of segment E of the Plaeners Formation
The contact with the Arenisca Tierna Formation is outlined (N: 1099257; E: 1082621; Z: 2807; azimuth: 20°)

4.1.4 Stratigraphic section of Alto del Gavilán

The measured thickness was 141.6 m. The coordinates of the starting point are N: 1111734; E: 1076950; Z: 2977 m a.s.l. The coordinates of the end point are N: 1111594; E: 1077100; Z: 3172 m a.s.l. The outcrop has an average N 60°E strike and 36° SE dip (Figure 17).

The section was divided into four segments (Figure 18), termed, from the base to the top, A, B, C, and D. Segments A and B, with a thickness of 66 m, correspond to the top of the Conejo Formation, and segments C and D, with a thickness of 75.6 m, correspond to the base of the Guadalupe Group. In this locality, the base of the Guadalupe Group generates a ridge that contrasts with the valleys of the Conejo and Plaeners formations (Figure 19).

In general, in this stratigraphic section, the base of the Guadalupe Group predominantly shows porcellanites and cherts with wackestone texture, with some layers of very fine-grained quartz arenites and quartz siltstones.

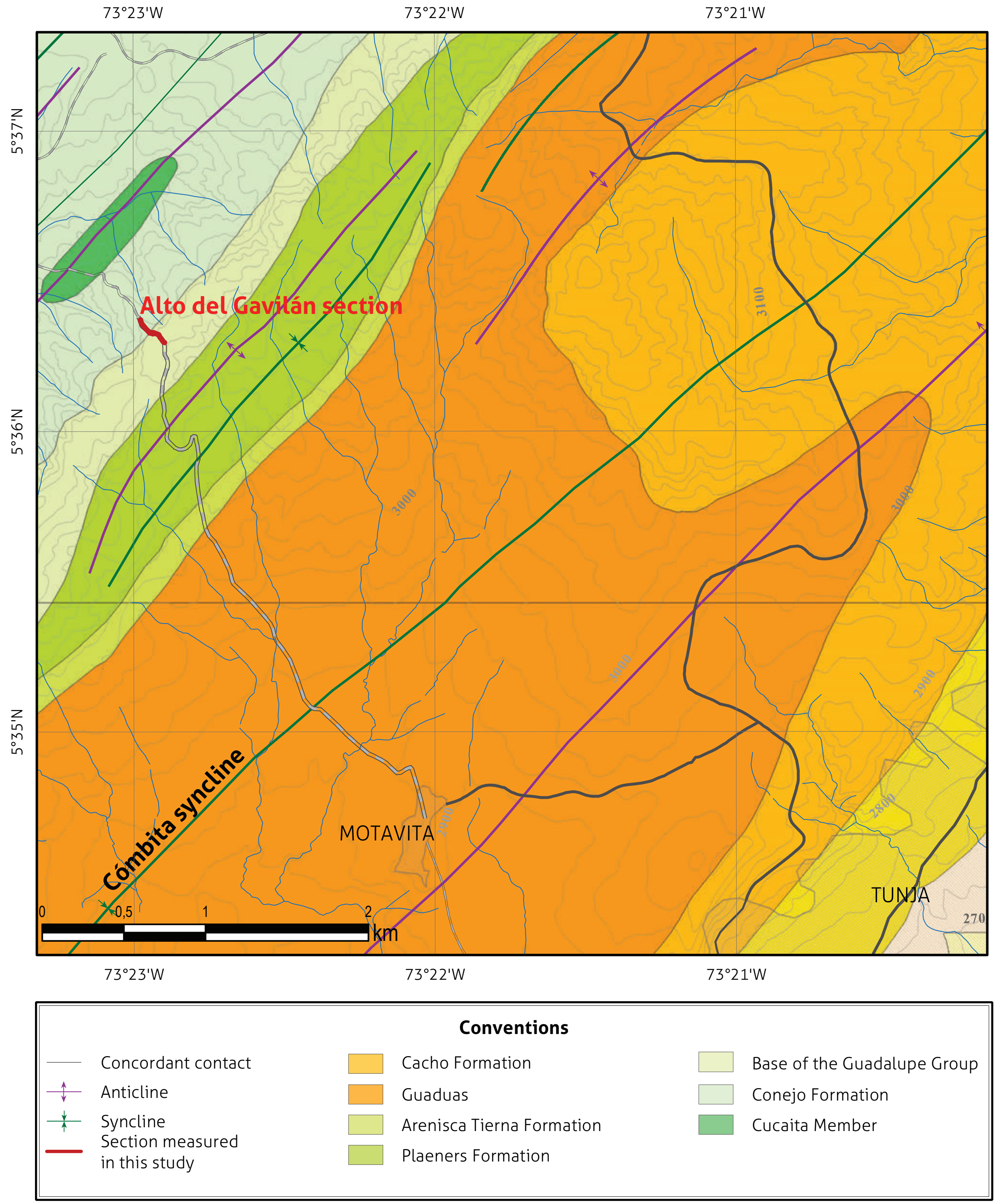

Figure 17. Location and local geology of the stratigraphic section of Alto del Gavilán
Source: geologic base map retrieved from Terraza et al. (2016)

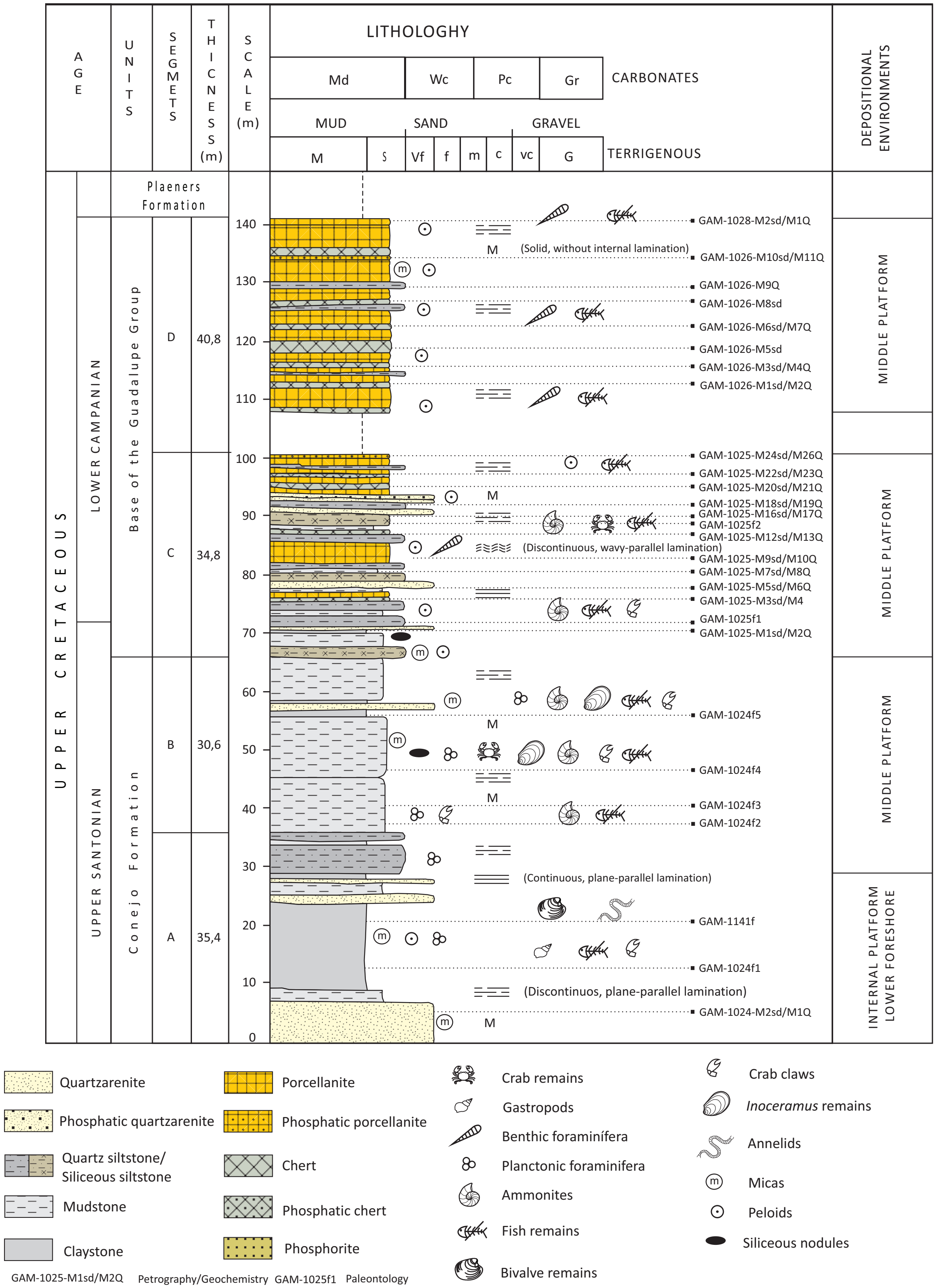

Figure 18. Stratigraphic section of Alto del Gavilán

Figure 19. SW view (Alto del Gavilán) showing the morphological contrast between the Conejo and Plaeners formations and the base of the Guadalupe Group (N: 1115657; E: 1080404; Z: 3081)

4.1.5 Conejo Formation

Segment A (0.0-35.4 m). The layers typically show continuous, plane-parallel bedding and very thin to thin, discontinuous, plane-parallel lamination, and the rocks are highly weathered. From the base to the top, segment A starts with a 6.9-m stratum of medium to very thick layers of very fine-grained, mature, pale-greenish-yellow quartz arenites with high bioturbation and sporadic layers of very fine-grained quartz arenites with discontinuous, wavy, nonparallel lamination, followed by a 2.4-m stratum of thin layers of very light-gray mudstones, continuing with 15 m of thin layers of brownish-gray claystones. Then a 1.7-m tabular layer of very fine-grained quartz arenites is followed by a 2-m layer of pale brown mudstones, by a 0.5-m tabular layer of very fine-grained quartz arenites, and by a 1.2-m layer of light-gray claystones, ending with 5.7 m of thin, medium, thick, and very thick layers of brownish-gray clayey siltstones (Figure 20). This interval contains planktonic foraminifera, fish remains, gastropods, crab claws, peloids, micas, and iron oxides.

Segment B (35.4-66.0 m). Segment B predominantly shows thin, medium, thick, and very thick layers of dark-yellowish-brown, brownish-gray, medium-brown, and medium-dark-gray mudstones with discontinuous to solid plane-parallel lamination and moderate to high bioturbation; sporadic thin, medium, and thick layers of dark-brown claystones; and tabular, medium to very thick layers of very fine-grained, medium-dark-gray quartz arenites with high bioturbation (Figure 21). This segment is characterized by the presence of ammonites such as "*Cocuyites cocuyensis* (Etayo-Serna, 1985), *Paratexanites* sp. inc., *Placenticeras* sp.? and the Upper Santonian bivalves *Meretrix eufaulensis*? (Conrad, 1860) and *Platyceramus* ex gr. *P. cycloides* (Wegner, 1905)" (Etayo-Serna, 2015). Some of these fossils are illustrated in Figures 21 and 22. Segment B also contains iron oxide concretions, siliceous nodules, planktonic foraminifera, crab claws, fish remains, organic matter, and micas.

Figure 20. Upper part of segment A and start of segment B of the Conejo Formation (N: 1111704; E: 1076962; Z: 3177; azimuth: 100°)

Figure 21. Base of segment B showing tabular, medium to thin layers of mudstones (a), with ammonites (b) and inoceramids (c) (N: 1111649; E: 1076026; Z: 3188)

Figure 22. Top of segment B of the Conejo Formation with layers of claystone (a) containing ammonite impressions shown in (b) and (c) (N: 1111676; E: 1076987; Z: 3186; azimuth: 95°)

4.1.6 Base of the Guadalupe Group

Segment C (66.0-100.8 m). The contact with the Conejo Formation (segment B) is net concordant (Figure 23). Segment B is characterized by continuous plane-parallel bedding and by very thin to thin, discontinuous, plane-parallel lamination.

The lower part of segment C starts with 1.7 m of thin to medium layers of siliceous siltstones, followed by 7.7 m of stratigraphic thickness with the following components: thin layers of mudstones and claystones (Figure 24) with siltstone nodules, followed by medium to thin layers of siliceous siltstones, with Lower Campanian ammonites such as "*Submortoniceras* sp. cf. *uddeni* (Young, 1963)" (Etayo-Serna, 2015), interspersed with tabular, thin layers of mudstones (Figure 25). Ascending stratigraphically, 1.5 m of thin to medium layers of porcellanites and cherts are followed by 5.7 m of the following lithology: medium layers of siltstones, followed by thin to medium layers of somewhat fossiliferous, very fine-grained quartz arenites with tabular geometry, and then thin to medium layers of siltstones with sporadic layers of porcellanites. Subsequently, 3.4 m of medium to thin layers of porcellanites containing quartz arenite nodules are followed by layers with chert nucleation, by a very thin layer of ferruginous grayish red siltstones, by a 0.9-m-thick stratum of thin to medium layers of siltstones, and by a 1.8-m-thick stratum of thin to medium layers of porcellanites and chert with foraminifera and peloid wackestone texture (Figure 26). These are interspersed with sporadic layers of quartz arenites and siliceous siltstones. Most rocks of this interval show the following colors: very light gray, brownish gray, pinkish gray and pale greenish yellow.

In the upper part of segment C, a fossil level of 1.2 m (Figure 27) consists of medium to thick layers of yellowish-gray mudstones, with impressions of ammonites such as *Submortoniceras uddeni*? (Young, 1963), suggesting the Lower Campanian (Etayo-Serna, 2015), and, as shown in Figure 27, fish and crab remains and peloids, followed by subtabular, thin to medium layers of sandy mudstone with high bioturbation (Figure 28). The upper part of segment C continues with a 7.8-m-thick stratum with the following structure: a thick and somewhat fossiliferous layer of quartz arenites, with nonvisible lamination, followed by thin layers of porcellanites with continuous, plane-parallel bedding and sporadic layers of chert; above, tabular, thin to medium layers of siliceous siltstones interspersed with a tabular, medium layer of chert with peloid wackestone texture (Figure 29) and nonvisible lamination, which are followed by thin to medium layers of porcellanites and by a tabular, medium layer of phosphatic porcellanite with peloid wackestone texture and nonvisible lamination. In this interval, the rocks are very light gray and pale greenish yellow. The upper part of segment C also contains benthic foraminifera, ammonite impressions, crabs, fish remains, peloids, micas, and iron oxides.

Figure 23. Contact between the Conejo Formation and the base of the Guadalupe Group, which corresponds to the boundary between segments B and C (N: 1111697; E: 1076987; Z: 3186; azimuth: 160°)

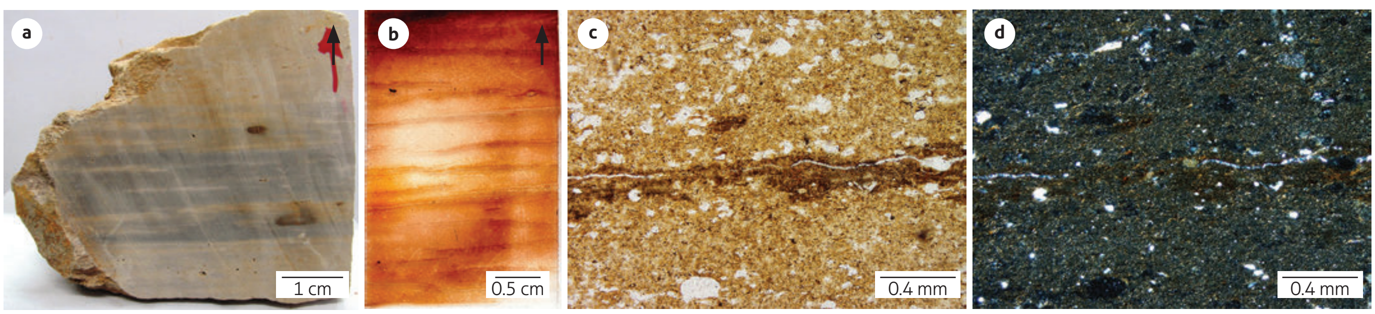

Figure 24. Sample GAM-1025-M1 sd of segment C, at 70.7 m
(a) Polished section of a laminated claystone. (b) Thin lamina of claystone showing discontinuous, wavy to plane-parallel lamination. Micrographs show crossed (c) and parallel nicols (d) showing clayey minerals with some floating quartz.

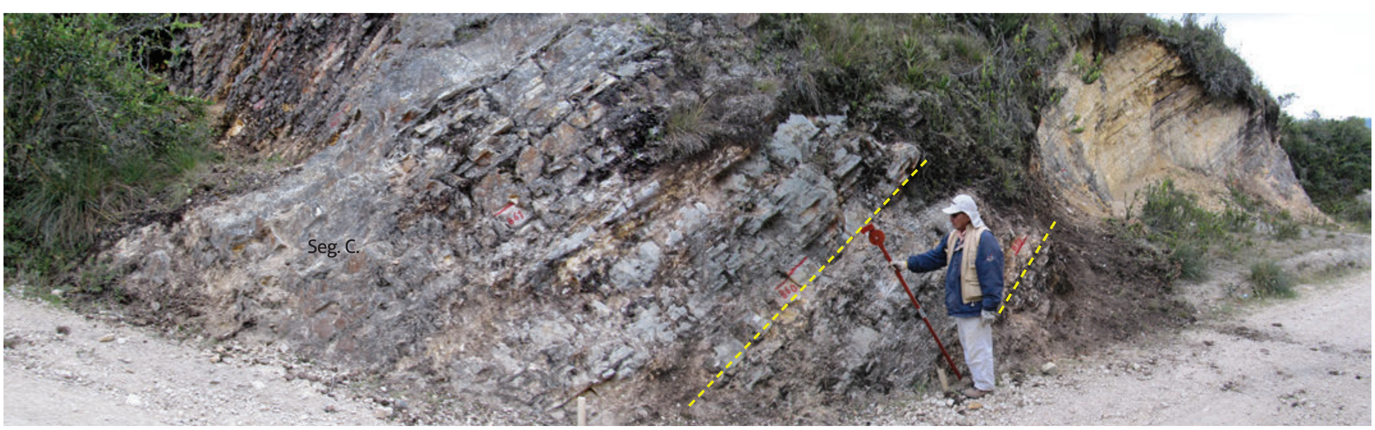

Figure 25. Base of segment C showing a fossiliferous level with ammonites in layers of siliceous siltstones and porcellanites (N: 1111649; E: 1077026; Z: 3188; azimuth: 255°)

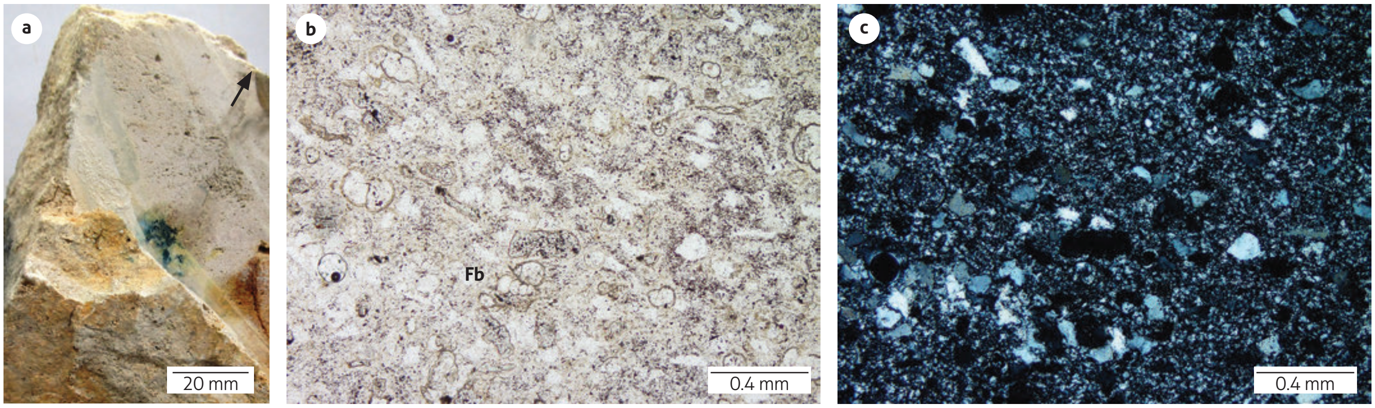

Figure 26. Sample GAM-1025-M12sd, 83.7 m, segment C
Polished section of a chert (a). The micrographs show benthic foraminifera (Fb) and bioclasts supported on finely crystalline quartz. Parallel (b) and crossed nicols (c).

Figure 27. Fossiliferous level of segment C (a) showing layers of siltstones and porcellanites, with ammonites magnified in b and c

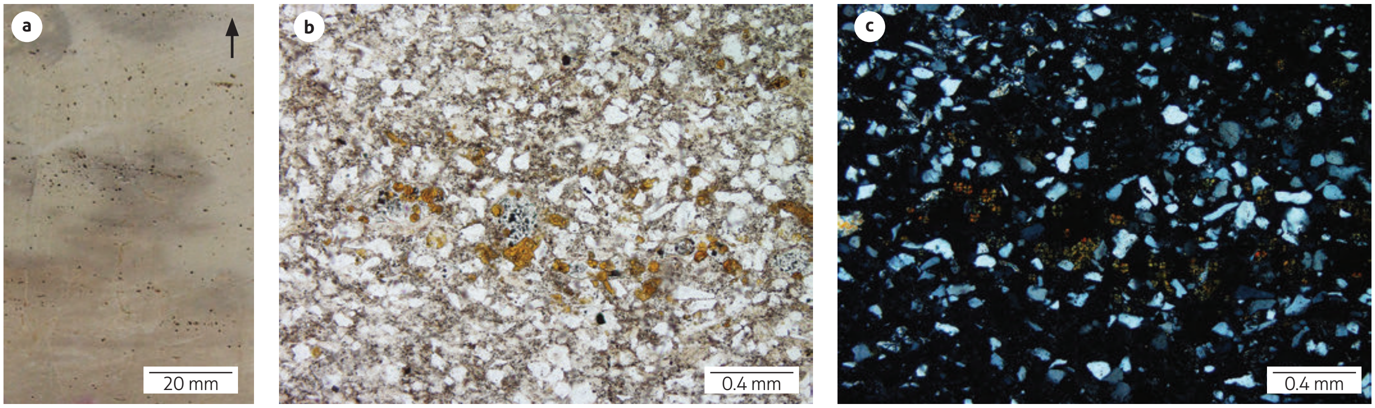

Figure 28. Sample GAM-1025-M14sd, segment C, 90 m
Polished section of a sandy mudstone (a). The micrographs show yellow grains of quartz and phosphates, supported by microcrystalline quartz and clayey minerals. Parallel (b) and crossed nicols (c).

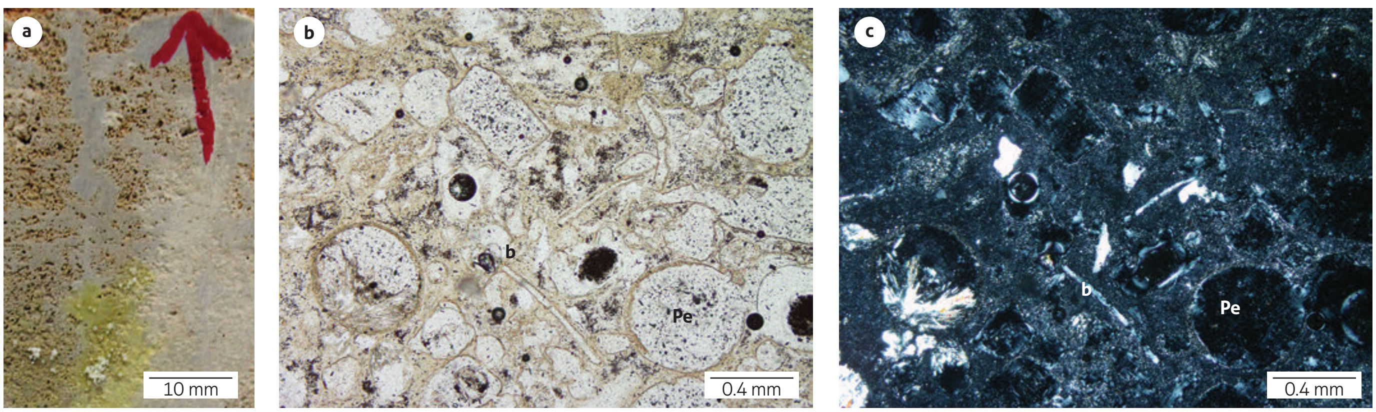

Figure 29. Sample GAM-1025-M22sd, segment C, 96.6 m
Polished section of a chert with peloid and bioclast wackestone texture (a). The micrographs show peloids (Pe) and bioclasts (b), supported by microcrystalline quartz (with chalcedony replacing peloids). Parallel (b) and crossed nicols (c).

Segment D (100.8-141.6 m). The outcrop generally presents continuous, plane-parallel bedding, and the layers show very thin to thin, nonvisible, discontinuous, plane-parallel lamination, predominantly with porcellanites (Figure 30). From the base to the top, the following sequence is identified: First, thin layers of porcellanites are interspersed with sporadic layers of chert and three wavy, intercalated, very thin layers of ferruginous, grayish-red siltstone. Then, thin to medium layers of siltstones are followed by thin to medium layers of porcellanites with tabular geometry, with sporadic layers of chert, siliceous siltstones, and two very thin layers of ferruginous siltstones. Next, a tabular, medium layer of fossiliferous porcellanite shows a peloid wackestone texture. At the top of the segment, tabular, thin to medium layers of fossiliferous porcellanite with a benthic foraminifera wackestone texture, interspersed with layers of chert, are followed by a covered zone with soft morphology that belongs to the Plaeners Formation. In this interval, the rocks show the following colors: very light gray, white, pinkish gray, and bluish white. The top of segment D also contains benthic foraminifera, fish remains, peloids, micas, and iron oxides.

Figure 30. Segment D, predominantly with tabular, thin, medium, and thick layers of porcellanites (N: 1111585; E: 1077080; Z: 3199; azimuth: 340°)

4.2 Results from XRD and XRF analysis

Within the stratigraphic interval that corresponds to the base of the Guadalupe Group, in the two stratigraphic sections measured in this study, systematic sampling was performed as follows: seventeen samples were collected in Vereda Salitre and nineteen in Alto del Gavilán. These samples were sent to the Laboratory of the SGC, where they were characterized mineralogically and geochemically by XRD and XRF. The results are outlined in Tables 2, 3, 4, and 5. The dashes shown in some of the cells of these tables indicate values below the detection limits of the diffraction and fluorescence equipment.

From the batch of samples collected at the base of the Guadalupe Group, in Vereda Salitre (Tables 2 and 3), the mineralogical analyses determined that eight samples are siliceous rocks (cherts and porcellanites) and that nine samples are siliciclastic rocks (claystones, mudstones, and quartz arenites). They have (detritic and silica) quartz contents ranging from 66.7 to 99.8%, as corroborated by geochemical data, which shows that silica (SiO_2) ranges from 62.6 to 95.7% (Figure 31). In conclusion, although the texture determined by petrographic analysis is typical of calcareous and phosphatic rocks (wackestone), minerals with calcium and phosphorus, such as hydroxyapatite and carbonatofluoroapatite, are only present in two samples. In general, throughout the stratigraphic interval, the values of calcium oxide (CaO) are lower than 4.0% (Figure 31), and the values of phosphoric oxide (P_2O_5) range from 0.2 to 5.4%.

Kaolinite is also detected, with values ranging from less than 2.0 to 21.3%, in line with the values of aluminum oxide (Al_2O_3), which range from 2.0 to 14.4%, as possible alteration products of aluminum silicates (Figure 31).

Table 2. Mineralogical results (XRD) of the samples collected in Vereda Salitre

Sample	Equivalent petrographic sample	In the section (m)	Quartz (%)	Kaolinite (%)	Muscovite (%)	Goethite (%)	Hydroxyapatite (%)	Wavellite (%)	Microcline (%)	Carbonate fluorapatite (%)	Rock classification, Folk (1954, 1974) y Williams et al. (1954)
GAM-1019-M22Q	GAM-1019-M21 sd	95.7	83.9	13.5	0.0	0.0	0.0	0.0	2.6	0.0	Mudstone
GAM-1019-M20Q	GAM-1019-M19sd	88.7	85.2	11.9	0.0	0.0	0.0	0.0	0.0	3.0	Mudstone
GAM-1019-M18Q	GAM-1019-M17sd	79.6	84.7	6.8	0.0	0.0	0.0	8.5	0.0	0.0	Porcellanite
GAM-1019-M16Q	GAM-1019-M15sd	77.7	90.5	_	3.1	0.0	0.0	0.0	4.6	0.0	Chert
GAM-1019-M14Q	GAM-1019-M13sd	74.6	81.2	7.2	5.7	0.0	0.0	0.0	5.9	0.0	Mudstone
GAM-1019-M12Q	Not collected	71.3	76.1	23.3	0.0	0.0	0.0	0.0	_	0.0	Quartz arenite
GAM-1019-M11Q	GAM-1019-M10sd	58.4	92.5	7.2	0.0	0.0	0.0	0.0	_	0.0	Porcellanite
GAM-1019-M9Q	GAM-1019-M8sd	54.8	80.2	10.4	0.0	0.0	7.4	0.0	_	0.0	Porcellanite
GAM-1019-M7Q	GAM-1019-M6sd	53.2	85.1	9.6	0.0	0.0	0.0	0.0	5.3	0.0	Mudstone
GAM-1019-M5Q	GAM-1019-M4sd	51.6	80.9	4.5	5.9	0.0	0.0	0.0	8.7	0.0	Mudstone
GAM-1019-M3Q	Not collected	43.5	66.7	20.6	12.7	0.0	0.0	0.0	0.0	0.0	Mudstone
GAM-1019-M2Q	GAM-1019-M1 sd	39.3	99.3	0.0	0.0	_	0.0	0.0	0.0	0.0	Chert
GAM-1018-M1Q	Not collected	39.0	70.3	14.7	0.0	15.1	0.0	0.0	0.0	0.0	Porcellanite
GAM-1017-M8Q	GAM-1017-M7sd	28.4	78.7	21.3	0.0	0.0	0.0	0.0	0.0	0.0	Claystone
GAM-1017-M6Q	GAM-1017-M5sd	20.8	91.4	8.6	0.0	0.0	0.0	0.0	0.0	0.0	Chert
GAM-1017-M4Q	GAM-1017-M3sd	14.7	93.2	6.8	0.0	0.0	0.0	0.0	0.0	0.0	Chert
GAM-1017-M2Q	GAM-1017-M1 sd	12.2	99.8	_	0.0	0.0	0.0	0.0	0.0	0.0	Chert

Table 3. Geochemical results (XRF) of the samples collected in Vereda Salitre

Sample	Equivalent petrographic sample	In the section (m)	SiO_2 (%)	TiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)	FeO (%)
GAM-1019-M22Q	GAM-1019-M21 sd	95.7	84.5	0.4	8.2	1.9	0.2	0.1	_	0.8	0.6	0.1
GAM-1019-M20Q	GAM-1019-M19sd	88.7	83.9	0.3	7.9	1.0	0.3	1.0	_	0.6	1.5	_
GAM-1019-M18Q	GAM-1019-M17sd	79.6	75.6	0.2	10.8	0.6	0.1	0.6	_	0.4	5.4	_
GAM-1019-M16Q	GAM-1019-M15sd	77.7	94.5	0.1	3.0	0.2	0.1	0.1	_	0.3	0.2	_
GAM-1019-M14Q	GAM-1019-M13sd	74.6	82.7	0.5	10.0	1.4	0.3	0.1	_	1.0	0.3	_
GAM-1019-M12Q	Not collected	71.3	77.1	0.6	13.4	1.7	0.5	0.1	_	1.2	0.6	_
GAM-1019-M11Q	GAM-1019-M10sd	58.4	90.2	0.3	5.0	1.5	0.1	0.1	_	0.4	0.3	_
GAM-1019-M9Q	GAM-1019-M8sd	54.8	78.4	0.4	7.1	2.2	0.2	3.6	_	0.7	3.7	_
GAM-1019-M7Q	GAM-1019-M6sd	53.2	86.2	0.4	6.9	1.6	0.1	0.1	_	0.9	0.9	_
GAM-1019-M5Q	GAM-1019-M4sd	51.6	81.7	0.4	8.6	3.3	0.3	0.1	_	1.1	0.8	_
GAM-1019-M3Q	Not collected	43.5	75.5	0.6	14.4	1.7	0.5	0.1	_	1.2	0.4	0.2
GAM-1019-M2Q	GAM-1019-M1 sd	39.3	91.7	0.1	2.0	3.8	0.1	0.1	_	0.2	0.2	_
GAM-1018-M1Q	Not collected	39.0	62.6	0.2	4.6	22.1	0.1	0.6	_	0.2	3.8	0.1
GAM-1017-M8Q	GAM-1017-M7sd	28.4	79.3	0.4	11.9	2.2	0.4	0.0	_	1.0	0.2	_
GAM-1017-M6Q	GAM-1017-M5sd	20.8	92.7	0.2	4.1	0.6	0.1	0.1	_	0.3	0.2	_
GAM-1017-M4Q	GAM-1017-M3sd	14.7	95.7	0.1	2.5	0.3	0.1	0.1	_	0.2	0.1	_
GAM-1017-M2Q	GAM-1017-M1 sd	12.2	95.7	0.1	2.4	0.4	0.1	0.1	_	0.2	0.1	_

Mineralogical analysis of the batch of samples collected at the base of the Guadalupe Group, in Alto del Gavilán (Tables 4 and 5), shows that 10 samples are siliceous (cherts and porcellanites) and six are siliciclastic, (claystones, mudstones, and quartz arenites). Their (detritic and silica) quartz at percentages range from 80.8% to 100%, as corroborated by the geochemical data, which show that silica (SiO_2) ranges from 79.2% to 98.5% (Figure 32). The three remaining samples (ferruginous siltstones) show quartz percentages lower than 50.0%, but they have high values of kaolinite (53.0%, 66.0% and 67.3%), hematite, and anatase. Although the texture of siliceous rocks, as determined by petrographic analysis, is typical of calcareous and phosphate rocks (wackestone), minerals with calcium are absent, and minerals with phosphorus, such as wavellite and variscite, are only present in seven samples, at very low percentages, lower than 6.8% (Figure 32). Calcium oxide (CaO) is present in amounts lower than 2.4%, and phosphoric oxide (P_2O_5) ranges from 0.04% to 15.1% (Figure 32).

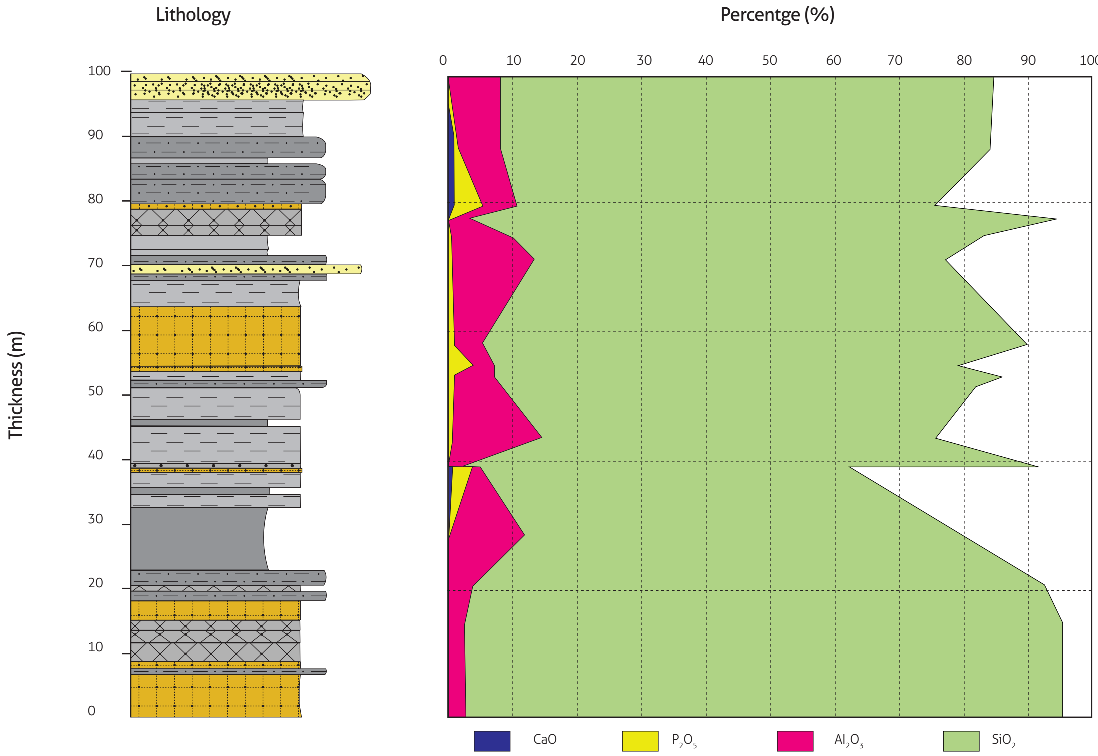

Figure 31. Curves of the percentages of major elements, SiO_2, Al_2O_3, CaO, and P_2O_5, determined by XRF, representing vertically the thickness of the base of the Guadalupe Group in Vereda Salitre

Table 4. Mineralogical results (XRD) of the samples collected in Alto del Gavilán

Sample	Equivalent petrographic sample	In the section (m)	Quartz (%)	Kaolinite (%)	Muscovite (%)	Sepiolite (%)	Greenalite (%)	Hematite (%)	Wavellite (%)	Microcline (%)	Variscite (%)	Anatase (%)	Rock classification, Folk (1954, 1974) and Williams et al. (1954)
GAM-1028-M1Q	GAM-1028-M2sd	141.0	91.3	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Porcellanite
GAM-1026-M11Q	GAM-1026-M10sd	134.5	98.8	_	0.0	0.0	_	0.0	0.0	_	0.0	0.0	Chert
GAM-1026-M9Q	Not collected	129.1	12.5	66.0	0.0	2.3	0.0	15.2	0.0	0.0	0.0	4.0	Ferruginous Siltstone
GAM-1026-M7Q	GAM-1026-M6sd	122.8	35.7	53.0	0.0	0.0	0.0	6.3	0.0	0.0	0.0	5.0	Ferruginous Siltstone
GAM-1026-M4Q	GAM-1026-M3sd	115.4	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Chert
GAM-1026-M2Q	GAM-1026-M1 sd	112.9	99.7	0.0	0.0	0.0	0.0	0.0	0.0	_	0.0	0.0	Chert
GAM-1025-M26Q	GAM-1025-M24sd	100.3	80.8	0.0	0.0	0.0	0.0	0.0	18.5	0.0	_	0.0	Porcellanite
GAM-1025-M23Q	GAM-1025-M22sd	96.6	93.2	0.0	0.0	0.0	0.0	0.0	6.8	_	0.0	0.0	Chert
GAM-1025-M21Q	GAM-1025-M20sd	95.4	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Chert
GAM-1025-M19Q	GAM-1025-M18sd	93.8	94.0	0.0	4.1	0.0	0.0	0.0	_	0.0	0.0	0.0	Quartz arenite
GAM-1025-M17Q	GAM-1025-M16sd	91.1	98.6	0.0	0.0	0.0	0.0	0.0	_	_	0.0	0.0	Quartz arenite
GAM-1025-M15Q	GAM-1025-M14sd	90.0	94.1	0.0	4.8	0.0	0.0	0.0	_	0.0	0.0	0.0	Mudstone
GAM-1025-M13Q	GAM-1025-M12sd	87.3	98.4	0.0	0.0	0.0	0.0	0.0	_	0.0	0.0	0.0	Porcellanite
GAM-1025-M11Q	Not collected	85.8	25.9	67.3	0.0	0.0	0.0	6.9	0.0	0.0	0.0	0.0	Ferruginous Siltstone
GAM-1025-M10Q	GAM-1025-M9sd	83.0	92.1	7.5	0.0	0.0	_	0.0	0.0	0.0	0.0	0.0	Chert
GAM-1025-M8Q	GAM-1025-M7sd	80.8	91.8	3.1	4.6	_	0.0	0.0	0.0	0.0	0.0	0.0	Mudstone
GAM-1025-M6Q	GAM-1025-M5sd	77.9	91.6	7.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Mudstone
GAM-1025-M4Q	GAM-1025-M3sd	76.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Chert
GAM-1025-M2Q	GAM-1025-M1 sd	70.7	88.5	11.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Claystone

Table 5. Geochemical results (XRF) of the samples collected in Alto del Gavilán

Sample	Equivalent petrographic sample	In the section (m)	SiO_2 (%)	TiO_2 (%)	Al_2O_3 (%)	TFe_2O_3 (%)	MgO (%)	CaO (%)	P_2O_5 (%)	K_2O (%)	Na_2O (%)	FeO (%)
GAM-1028-M1Q	GAM-1028-M2sd	141.0	91.1	0.2	5.1	0.7	0.1	0.1	0.2	_	_	0.3
GAM-1026-M11Q	GAM-1026-M10sd	134.5	93.8	0.1	3.7	0.4	0.1	0.1	0.1	_	_	0.3
GAM-1026-M9Q	Not collected	129.1	36.3	0.8	25.2	26.5	0.3	0.1	0.6	_	_	1.1
GAM-1026-M7Q	GAM-1026-M6sd	122.8	50.0	1.0	19.0	19.6	0.3	0.1	0.8	_	_	0.7
GAM-1026-M4Q	GAM-1026-M3sd	115.4	84.8	0.1	6.9	0.7	0.4	2.4	1.9	_	_	0.3
GAM-1026-M2Q	GAM-1026-M1 sd	112.9	95.8	0.1	2.3	0.4	0.1	0.1	0.1	0.2	_	0.2
GAM-1025-M26Q	GAM-1025-M24sd	100.3	55.4	0.1	17.7	1.1	0.1	0.1	15.1	0.3	_	0.3
GAM-1025-M23Q	GAM-1025-M22sd	96.6	79.2	0.1	8.7	0.6	0.1	0.1	5.3	_	_	0.4
GAM-1025-M21Q	GAM-1025-M20sd	95.4	98.5	0.0	0.7	0.3	0.1	0.1	0.0	_	_	_
GAM-1025-M19Q	GAM-1025-M18sd	93.8	84.1	0.2	6.9	1.2	0.2	0.1	3.2	0.2	_	0.4
GAM-1025-M17Q	GAM-1025-M16sd	91.1	92.5	0.2	3.5	0.6	0.1	0.1	1.4	_	_	0.2
GAM-1025-M15Q	GAM-1025-M14sd	90.0	88.7	0.3	5.4	1.1	0.3	0.1	1.0	_	_	0.6
GAM-1025-M13Q	GAM-1025-M12sd	87.3	88.8	0.2	5.4	1.3	0.2	0.1	1.1	_	_	0.6
GAM-1025-M11Q	Not collected	85.8	46.4	0.7	26.0	13.9	0.7	0.1	0.9	0.2	_	2.2
GAM-1025-M10Q	GAM-1025-M9sd	83.0	91.4	0.2	4.9	0.6	0.2	0.1	0.3	_	_	0.5
GAM-1025-M8Q	GAM-1025-M7sd	80.8	90.1	0.1	5.1	0.9	0.2	0.1	0.8	_	_	0.6
GAM-1025-M6Q	GAM-1025-M5sd	77.9	89.3	0.1	5.3	1.2	0.2	0.1	1.2	0.2	_	0.4
GAM-1025-M4Q	GAM-1025-M3sd	76.0	95.9	0.0	2.4	0.3	0.1	0.1	0.1	0.2	_	0.2
GAM-1025-M2Q	GAM-1025-M1 sd	70.7	87.7	0.2	7.1	0.9	0.3	0.1	0.2	0.2	_	0.8

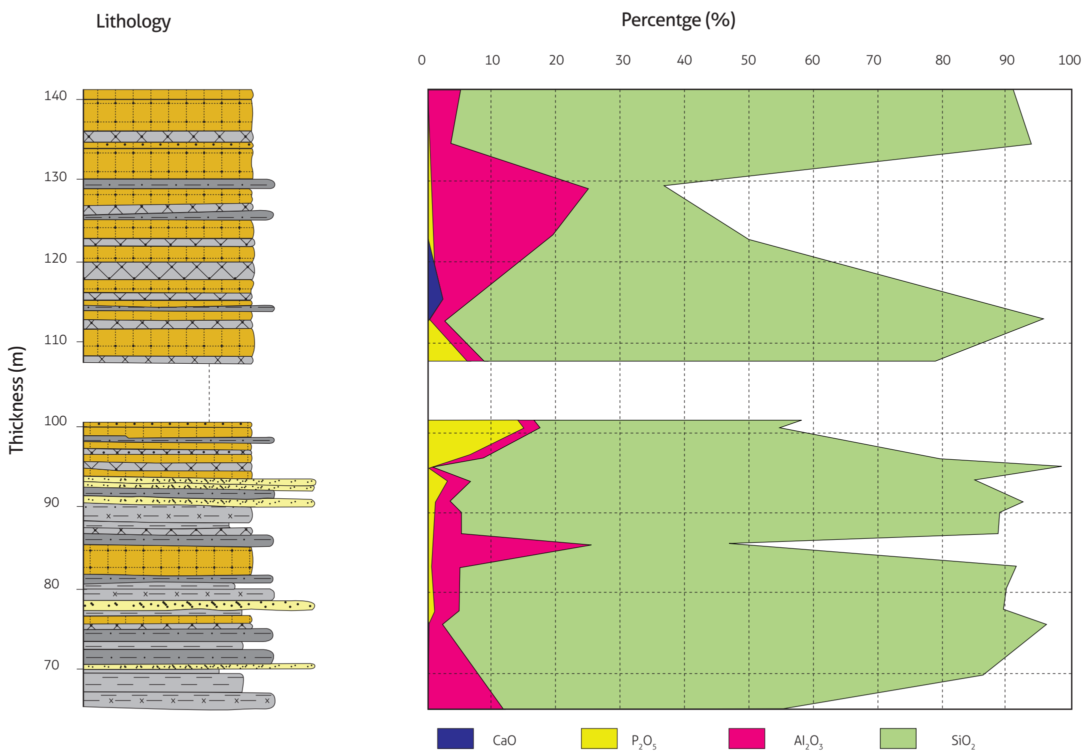

Figure 32. Curves of the percentages of major elements, SiO_2, Al_2O_3, CaO, and P_2O_5, determined by XRF represented horizontally, representing vertically the thickness of the base of the Guadalupe Group in Alto del Gavilán

5. Discussion

The stratigraphic nomenclature corresponding to the Guadalupe Group, in the Tunja area of Colombia, established by Renzoni (1981) and by Renzoni et al. (1976), divided the Guadalupe Group into the Plaeners Formation (kg2) in the base and the Labor-Tierna Formation (kg1) in the top. These authors thought that the Arenisca Dura Formation (kg3) of the Bogotá savanna would be included in the layers of sandstones of the top of the Conejo Formation of this locality. However, the base of the Guadalupe Group, the object of this study, mostly dates back to the Lower Campanian (Etayo-Serna, 2015) and corresponds to the Plaeners Formation (kg2) of Renzoni (1981). In addition, stratigraphically, above the base of the Guadalupe Group, a soft unit of the Upper Campanian (Etayo-Serna, 2015) is overlaid by a set of quartz arenites representing the Plaeners and Arenisca Tierna formations of the Bogotá savanna, included by Renzoni in unit kg1, in this part of the eastern Andes of Colombia (see Figure 1). In the Guadalupe Group of Tunja and its surrounding area, three clearly distinguishable and easily recognizable units can be lithologically and geomorphologically identified. The base of these units (described in this article) differs substantially from the type section in the Eastern Hills of Bogotá. To avoid confusion with the nomenclature proposed by Renzoni (1981), for the moment, the unit in question should be informally designated as "base of the Guadalupe Group" while deciding whether to maintain the nomenclature of Montoya and Reyes (2003 a, b; 2005 a, b; 2007) for this area of the Eastern Andes of Colombia.

The petrographic analysis performed by Martínez (2018) at the base of the Guadalupe Group, in the two stratigraphic sections described in this study, showed that most cherts and porcellanites with wackestone or mudstone texture with allochems replaced by microcrystalline quartz and chalcedony, with microcrystalline quartz support, correspond to calcareous or phosphate rocks (biomicrites and biopelmicrites), which underwent a process of replacement of the calcareous mud (micrite) and pre-existing allochems by silica, possibly during the final stage of diagenesis (compaction).

6. Conclusions

In the Tunja area of Colombia, the Guadalupe Group has morphologically and lithologically differentiated into three units: two hard units that originate ridges corresponding to the base of the Guadalupe Group and the Arenisca Tierna Formation, respectively, with a soft unit in the middle that generates a characteristic valley in the Plaeners Formation.

The paleontological analyses performed on the two stratigraphic sections measured in this study (Etayo-Serna, 2015) indicate that the base of the Guadalupe Group partly represents the Upper Santonian and mostly the Lower Campanian.

Acknowledgments

The authors thank Gloria Prieto Rincón, the Director of the Dirección de Recursos Minerales of the SGC, for the unconditional support for our research group during the activities conducted in this study and the assessment of the results; doctor Fernando Etayo Serna for the valuable contribution through the paleontological determination of the ammonites collected in the two stratigraphic sections measured in this study; the staff members of the Dirección de Laboratorios of the SGC, for the geochemical analysis and preparation of thin sections from samples collected in the two stratigraphic sections; the geographer Hernán Guillermo Cifuentes, for his help with the Geographic Information System; the geologists Nadia Rojas and Claudia Martín, for their help with the geologic mapping of the Tunja area; doctor Mario Maya Sánchez, editor of the journal *Boletín Geológico* of the SGC, for his recommendations and suggestions about the writing of this manuscript; and Mr. Franklin Lugo Buendía ("*Chicharrito*"), for his help with the field work and wise advice.

References

Baccelle, L., & Bosellini. A. (1965). Diagrammi per la stima visiva della composizione percentuale nelle rocce sedimentarie. *Annali della Universitá di Ferrara*, Sezione IX, Science Geologiche e Paleontologiche.

Bürgl, H. (1959). *Estratigrafía y estructura de la región entre Chía y Tenjo, Cundinamarca. Revisión del informe 1299*. Servicio Geológico Nacional.

Campbell, C. (1967). Lámina, laminaset, bed and bedset. Sedimentology. Oxford. https://doi.org/10.1111/j.1365-3091.1967.tb01301.x

Conrad, T. (1858). Observations on a group of Cretaceous fossil shells, found in Tippah County, Miss., with descriptions of fifty-sis new species. *Journal of the Academy of Natural Sciences of Philadelphia*, *3*(2), 323-336.

Conrad, T. (1860). Description of new species of Cretaceous and Eocene fossils of Mississippi and Alabama. *Journal of the Academy of Natural Sciences of Philadelphia*, *2*(4), 275-298.

D'Orbigny, A. D., & Boussingault, J. B. (1842). *Coquilles el échinodermes fossiles de Colombie (Nouvelle-Grenade), recueillis de 1821 à 1833*. P. Bertrand.

Dunham, R. (1962). Classification of carbonate rocks according to depositional textures. In W. E. Ham (Ed.), *Classification of carbonate rocks* (pp. 108-121). Memoir 1. American Association of Petroleum Geologists.

Etayo-Serna, F. (1964). Posición de las faunas en los depósitos cretácicos colombianos y su valor en la subdivisión cronológica de los mismos. *Boletín de Geología*, (16-17), 36-37.

Etayo-Serna, F. (1968a). Sinopsis estratigráfica de la región de Villa de Leyva y zonas próximas. Universidad Industrial de Santander. *Boletín de Geología*, (21), 19-32.

Etayo-Serna, F. (1968b). El sistema Cretáceo en la región de Villa de Leyva y zonas próximas. Universidad Nacional de Colombia. *Geología Colombiana* (5), 5-74.

Etayo-Serna, F. (1969). *Lenticeras baltai* Lisson en Colombia y su probable posición zonal santoniana. Universidad Nacional de Colombia. *Geología Colombiana*, 6, 17-32.

Etayo-Serna, F. (1985). *Paleontología estratigráfica del Sistema Cretácico en la Sierra Nevada del Cocuy. Proyecto Cretácico, contribuciones.* Publicaciones Geológicas Especiales. Ingeominas.

Etayo-Serna, F. (2015). *Estudios paleontológicos y bioestratigráficos de apoyo a la "Exploración de fosfatos en la cordillera Oriental, bloque Boyacá. Proyecto de investigación y exploración de recursos minerales no metálicos e industriales"*. Servicio Geológico Colombiano.

Folk, R. (1954). The distinction between grain size and mineral composition in sedimentary rock nomenclature. *Journal of Geology*, *62*(4), 344-359. https://doi.org/10.1086/626171

Folk, R. (1962). Spectral subdivision of limestone types. In W. E. Ham (Ed.), *Classification of carbonate rocks* (pp. 62-84). Memoir 1. American Association of Petroleum Geologists.

Folk, R. (1974). *Petrology of sedimentary rocks*. Hemphill Publishing Co.

Föllmi, K., Garrison, R., Ramírez, P., Zambrano F., Kennedy, W., & Lehner, B. (1992). Cyclic phosphate- rich successions in the upper Cretaceous of Colombia. *Paleogeography, Paleoclimatology, Paleoecology*, *93*(3-4), 151-182. https://doi.org/10.1016/0031-0182(92)90095-M

Geological Society of America. (1991). *Rock color chart. With genuine Munsell® color chips*.

Geological Society of London. (1990). Tropical residual soils: Geological Society Engineering Group Working Party Report. *Quarterly Journal of Engineering Geology and Hydrogeology*, *23*(1), 4-101. https://doi.org/10.1144/GSL.QJEG.1990.023.001.01

Guerrero, J., & Sarmiento, G. (1996). Estratigrafía física, palinológica, sedimentológica y secuencial del Cretáceo Superior y Paleoceno del piedemonte llanero. Implicaciones en exploración petrolera. *Geología Colombiana*, *20*, 3-66.

Hettner, A. (1892). *La cordillera de Bogotá: Resultado de viajes y estudios* (Trad. E. Gühl). Spanish version published in 1966. Banco de la República.

Hubach, E. (1931). *Geología petrolífera del departamento de Norte de Santander. Compilación de Estudios Geológicos Oficiales en Colombia.* Vol. XII. Ingeominas.

Hubach, E. (1951). *Estratigrafía de la sabana de Bogotá y sus alrededores*. Report 785. Servicio Geológico Nacional.

Hubach, E. (1957). *Contribución a las unidades estratigráficas de Colombia*. Internal report I-1212. Instituto Geológico Nacional.

Kennedy, W., Herbert, C., & Herber, S. (1981). Cretaceous faunas from Zululand and Natal, South Africa. Additional observations on the ammonite subfamily Texanitinae Collignon, 1948. *Annals of the South African Museum*, 8, 1-357.

Kennedy, W., Michel, B., & Patrice, M. (1995). Ammonite faunas, biostratigraphy and sequence stratigraphy of the Coniacian – Santonian of the Corbières (NE Pyrénées). *Bulletin des Centres de Recherches, Exploration et Production Elf-Aquitaine*, 19.

Krumbein, W., & Sloss, L. (1969). *Estratigrafía y sedimentación*. Ed Uteha.

Lazar, O., Bohacs, K., Macquaker, J., Schieber, J., & Demko, T. (2015). Capturing key attributes of fine-grained sedimentary rocks in outcrops, cores, and thin sections: Nomenclature and description guidelines. *Journal of Sedimentary Research*, *85*(3), 230-246. https://doi.org/10.2110/jsr.2015.11

Martínez, G. (2018). *Estudio de la base del Grupo Guadalupe en la región central de la cordillera Oriental, entre Ventaquemada y Toca, Boyacá, Colombia* (tesis de maestría). Universidad Nacional de Colombia.

Meek, F., & Hayden, F. (1857). Descriptions of new species and genera of fossils, collected by Dr. F. V. Hayden in Nebraska Territory, under the direction of lieut. GK Warren, US topographical engineer; with some remarks on the Tertiary and Cretaceous formations of the North-West, and the parallelism of the latter with those of other portions of the United States and territories. *Proceedings of the Academy of Natural Sciences of Philadelphia*, *9*, 117-133.

Montoya, D., & Reyes, G. (2003a). *Geología de la Plancha 209-Zipaquirá*. Ingeominas.

Montoya, D., & Reyes, G. (2003b). *Mapa geológico de la Plancha 209, Zipaquirá, escala 1:100.000*. Ingeominas.

Montoya, D., & Reyes, G. (2005a). *Geología de la sabana de Bogotá*. Ingeominas.

Montoya, D., & Reyes, G. (2005b). *Mapa geológico de la sabana de Bogotá, escala 1:100.000*. Ingeominas.

Montoya, D., & Reyes, G. (2007). *Geología de la sabana de Bogotá*. Publicaciones Geológicas Especiales, vol. 28. Ingeominas.

Moore, D., & Scrutton, P. (1957). Minor internal structures of recent unconsolidated sediments. *AAPG Bulletin*, *41*(12), 2753-2751. https://doi.org/10.1306/0BDA-59DB-16BD-11D7-8645000102C1865D

Pérez, G., & Salazar A. (1978). Estratigrafía y facies del Grupo Guadalupe. *Geología Colombiana*, *10*, 6-85.

Pettijohn, F., Potter, P., & Siever, R. (1973). *Sand and sandstone*. Springer-Verlag.

Pratt, S., Rowlinson, N., Aitken, B., Anderson, W., Babcock, C., Campbell, C., & Maher, P. (1961). *The Muzo emerald mine.* Second Anual Field Conference. Colombian Society of Petroleum Geologists and Geophysicists.

Reineck, H., & Singh, I. (1980). *Depositional sedimentary environments*. Springer-Verlag.

Renzoni, G. (1962). Apuntes acerca de la litología y tectónica de la zona al este y sureste de Bogotá. *Boletín Geológico*, *10*(1-3), 73-75.

Renzoni, G. (1981). Geología del cuadrángulo J-12, Tunja. *Boletín Geológico*, *24*(2), 31-48.

Renzoni, G., Rosas, H., & Etayo-Serna, F. (1976). *Geología de la Plancha 191, Tunja*. Ingeominas.

Taylor, J. (1950). Pore-espace reduction in sandstone. *AAPG Bulletin*, *34*(4), 701-706. https://doi.org/10.1306/3D933F47-16B1-11D7-8645000102C1865D

Terraza, R., Martin, C., Martínez, G., & Rojas, R. (2016). *Exploración geológica de fosfatos en el Bloque Boyacá, planchas 191 y 210*. Servicio Geológico Colombiano.

Terraza, R., Moreno, G., Buitrago, J., Pérez, A., & Montoya, D. (2010). *Geología de la Plancha 210, Guateque*. Ingeominas.

Wegner, T. (1905). Die Granulatenkreide des westlichen Münsterlandes. *Zeitschrift der Deutschen Geologischen Gesellschaft Band*, 57, 112-232.

Whitfield, R. (1877). *Preliminary report on the paleontology of the Black Hills, containing descriptions of new species of fossils from the Potsdam, Jurassic, and Cretaceous formations of the Black Hills of Dakota*. Geologial Survey of the Rocky Mountain region. https://doi.org/10.5962/bhl.title.55132

Whitfield, R. (1880). Paleontology of the Black Hills of Dakota. In H. Newton y W. P. Jenney (Eds.), *Report on the geology and resources of the Black Hills of Dakota* (pp. 325-468). Government Printing Office. https://doi.org/10.3133/70039917

Williams, H., Turner, F., & Gilbert, C. (1954). *Petrography and introduction to the study of rocks in thin sections*. University of California.

Young, K. (1963). *Upper Cretaceous ammonites from the Gulf Coast of the United States*. The University of Texas, Austin, Bureau of Economic Geology, Publication 6304.