Stratigraphic and petrographic study of the limestones of the La Tomita sector, in the municipality of Manaure-Cesar, Colombia

Estudio estratigráfico y petrográfico de las calizas del sector La Tomita, en el municipio de Manaure Cesar, Colombia

DOI: http://doi.org/10.17981/ingecuc.18.1.2022.11

Artículo de Investigación Científica. Fecha de Recepción: 16/11/2019. Fecha de Aceptación: 21/08/2022.

Génesis Carolina De Los Reyes Díaz
Fundación Universitaria del Área Andina. Valledupar (Colombia)
gd2@areandina.estudiantes.edu.co

Zamir Mendoza Mejía
Fundación Universitaria del Área Andina. Valledupar (Colombia)
zamendoza@areandina.estudiantes.edu.co

Eloy I. Mosquera Nieves
Fundación Universitaria del Área Andina. Valledupar (Colombia)
emosquera3@areandina.estudiantes.edu.co

Elías Ernesto Rojas Martínez
Fundación Universitaria del Área Andina. Valledupar (Colombia)
eliaser@hotmail.com

Dino Carmelo Manco Jaraba
Universidad de La Guajira. Riohacha (Colombia)
dinomancojaraba@gmail.com

Frank Lascarro Navarro
Universidad Mayor de San Marcos. Lima (Perú)
Frank.lascarro@unmsn.edu.pe

To cite this paper:
G. De los reyes Díaz, Z. Mendoza Mejía, E. Mosquera Nieves, E. Rojas Martinez, D. Manco Jaraba & F. Lascarro Navarro, "Stratigraphic and petrographic study of the limestones of the La Tomita sector, in the municipality of Manaure-Cesar, Colombia," *INGE CUC*, vol. 18, no. 1, pp. 129–141, 2022. DOI: http://doi.org/10.17981/ingecuc.18.1.2022.11

Abstract

Introduction— In the La Tomita sector, municipality of Manaure (Cesar), outcrop a stratigraphic sequence of biomicrite limestones, biopelmicrites, pelmicrites, wackestones and packstones intercalated with shales, corresponding to the Lagunita Formation of the Cogollo Group.

Objective— To know the stratigraphic aspects, mineralogical composition and paleoenvironmental conditions of the outcropping limestones.

Methodology— It proceeded with a lithostratigraphic description in the massif and taking samples in situ, twelve samples were extracted, of which seven were taken for petrographic analysis.

Results— Wackestone facies with pelagic microfossils, bioclastic packstone, wackestone with worn mollusc bioclasts and wackestone with peloids were recognized. Petrographically, the limestones in this sector are made up of zircon, glauconite, sparite, micrite, pellets, planktonic foraminifera of the genus Heterohelix, of the Moremani species, and foraminifera of the genus Hedbergella and Trocoidea species. Bivalve fossils and some algae were also observed.

Conclusions— These facies allowed establishing that these limestones were formed in an environment of medium platform with some external platform intervals, covering an area of facies of open sea.

Keywords— Limestone; Stratigraphy; Manaure; Petrography; Shales

Resumen

Introducción— En el sector de La Tomita, municipio de Manaure (Cesar), aflora una secuencia estratigráfica de calizas biomicritas, biopelmicritas, pelmicritas, wackestones y packstones intercalados con lutitas, correspondientes a la Formación Lagunita del Grupo Cogollo.

Objetivo— Conocer los aspectos estratigráficos, la composición mineralógica y las condiciones paleoambientales de las calizas aflorantes.

Metodología— Se procedió a la descripción litoestratigráfica en el macizo y a la toma de muestras in situ, se extrajeron doce muestras, de las cuales se tomaron siete para su análisis petrográfico.

Resultados— Se reconocieron facies de wackestone con microfósiles pelágicos, packstone bioclástico, wackestone con bioclastos de moluscos desgastados y wackestone con peloides. Petrográficamente, las calizas de este sector están compuestas por circón, glauconita, esparita, micrita, pellets, foraminíferos planctónicos del género Heterohelix, de la especie Moremani, y foraminíferos del género Hedbergella y de la especie Trocoidea. También se observaron fósiles de bivalvos y algunas algas.

Conclusiones— Estas facies permitieron establecer que estas calizas se formaron en un ambiente de plataforma media con algunos intervalos de plataforma externa, cubriendo un área de facies de mar abierto.

Palabras clave— Caliza; Estratigrafía; Manaure; Petrografía; Pizarras

I. Introduction

The Perija Mountain Range (SP) is a mountainous system located in the North-Northeast region of Colombia. It comprises an elongated mountainous structure that originated from the uplift of the terrain caused by the Andean orogeny, consisting of rocks with ages from the Cambrian-Ordovician to the recent. Formed essentially by metamorphic rocks and predominantly by sedimentary rocks on the surface [1].

In the jurisdiction of the municipality of Manaure (Colombia) is the village of La Tomita, characterized by presenting outcrops of carbonate rocks type wackestones and packstones interspersed with salts [1], [2], along the river Manaure. These rocks are part of the "Undifferentiated Cretaceous limestones and shales Unit", described by Colombian institutions [3], which in turn is divided into the Lagunitas, Aguas Blancas (Cogollo Group) and La Luna Formation.

This Unit presents the difficult lithological distinction between the Lagunitas and Aguas Blancas, because the Aguas Blancas Formation [4], presents a great lithological variation, vertically and laterally. This is explained because the Cesar-Ranchería Basin had a mixture of different sources of terrigenous contribution, to the southeast and southwest clays and carbonates to the northeast, as a consequence several authors prefer to consider the Cogollo Group or as a single unit without making differences [5].

Authors such as SGC [6], refer that the La Luna Formation has compositional similarity with the rocks of the Cogollo Group, however, its petrographic characteristics allow its lithostratigraphic differentiation. While Venezuelan studies [5], they specify that the Maracas Member of the Aguas Blanca Formation of the Cogollo Group is very difficult to differentiate from the La Luna Formation in cores, hand samples and outcrops; but from electrical records its recognition is facilitated by the decrease in resistivity that the La Luna Formation presents.

Authors such as Ingeominas [3] or Geoestudios Ltda. [7] have chosen, given the difficulty of differentiating the Members of the Formations that constitute the Cogollo Group with the La Luna Formation in some sectors of the Cesar-Ranchería Basin, to use the term "Undifferentiated Cretaceous limestones and shales" to the set of carbonate rocks interspersed with shales.

For this reason, the present research aims to identify and describe petrographically and stratigraphically the Formations and their genetic environment in the study area.

II. Location

The study area is located in the Colombian Caribbean region, towards the northeastern part of the Cesar department and the western part of the Perija Mountain Range. Framed within the La Tomita village of the Manaure municipality, approximately 7.8 km from the La Paz municipality and 9 km from the Manaure Balcón del Cesar urban area, towards the southern part of the Manaure river, covering a cartographic area of an extension 15 km^2 (Fig. 1).

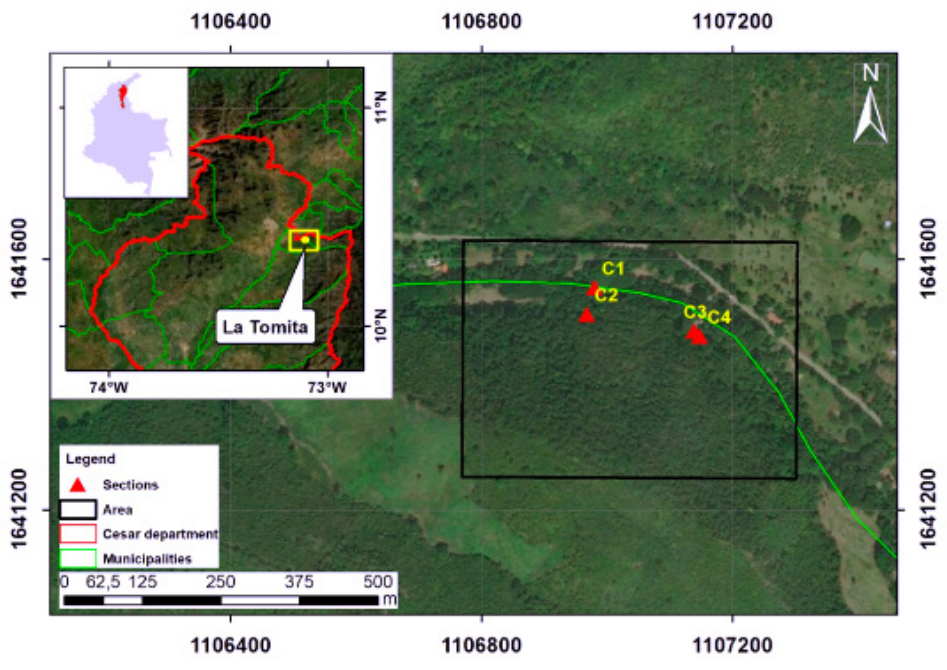

Fig. 1. Location of the research area.
Source: Authors.

III. Methodology

In order to fulfill the objectives of the research, a geological mapping review of the area and a stratified sampling were carried out. Stratified sampling consisted of selecting samples by layers or strata in the lower, middle and upper parts of the outcrop with a size not less than 80 linear cm, considering the homogeneity of the strata, following the methodology proposed in the Cretaceous Project research carried out by Ingeominas [8].

It was identified as a sedimentary record on the Manaure River, to facilitate its stratigraphic survey, it was divided into 4 sections C1, C2, C3, and C4 based on lithological criteria and paleontological content. In the C1 sections, C2, and C3, the base sequence denominating segment A, in section C4 was determined the top of the sequence designated segment B. Describing characteristics found which allowed determining the depositional environment of the sequence.

The petrographic studies established textural and compositional elements that facilitated the differentiation of the limestone of the sequence according to the macroscopic and microscopic characteristics, based on the textural classification [9]. For compositional classification according to American studies [10], [11] in addition to the identification of foraminifera species that allow the correlation and assignment of relative ages of the outcropping rocks.

In total 47 samples were collected, 36 samples in segment A (one sample per stratum), and 11 samples in segment B (one sample per stratum). 16 samples were used for textural description and 7 samples for micro-petrographic analysis; taking into account the state of the rocks (fresh/healthy or with signs of incipient weathering).

IV. Regional geology

Cesar department is comprised of three geologically important areas, the Santa Marta massif, the Perija Mountain Range and the river Cesar basin. Perija Mountain Range has an area of approximately 425 km, presenting an altitude of 500 meters to 3 550 meters above sea level, located at the northwest of South America, between Colombia and part of Venezuela territory, its limits are given to the north by Oca Fault to the south by the Santa Marta-Bucaramanga Fault [12], [13].

The geology in the Perija Mountain Range is highly variable with respect to the age of the lithological units, which leads to different considerations being made in this regard. An example is the one made by Ingeominas [14], which suggests that the rocks present in this region were formed from the Jurassic to the Tertiary, meanwhile UNAL [15] consider that the ages of the Units are comprised from the Paleozoic period to the Quaternary and that it is possible to find marine and continental sediments in outcrops in the region.

The description of the Formations included in the Unit “Undifferentiated Cretaceous Limestones and Shales” present in the Manaure-Cesar region is set out below.

A. *Cogollo Group*

The Cogollo Group was initially described in the CSS [16], grouping a series of calcareous rocks (limestone, sandy limestone and calcareous sandstone) of Barremian-Aptian age that are part of the western edge of Perija Mountain Range. Characterized by presenting its lower contact with the La Quinta Formation in a discordant way, and gradational with the Río Negro Formation [17], [18].

This group is lithologically divided into the Lagunitas (Base) and Aguas Blancas (Top) Formations, which in turn is subdivided into three members known as Ánimas, Tucuy and Maracas [18], [19], [20].

B. *Lagunita Formation*

Described as a succession of massive, dark gray limestones with a high content of fossils, with small alternations of calcareous mudstones and lumachelic limestones [19], with a maximum measured thickness of 290 meters [21].

C. *Aguas Blancas Formation*

It groups from base to top three Members characterized by Ánimas: made up of a calcareous mudolithic complex with abundant organic matter interspersed with black micritic limestones that horizontally grade into carbonate sandstones of fine sand grain with a thickness of 285 meters. Tucuy: made up of carbonated sandy siltstones, fine sand grained sandstones and calcareous claystones, its thickness is 450 meters; and Maracas: composed of massive lumachelic limestones, with a thickness of 217 meters [18], [20].

D. *La Luna Formation*

Initially described by some research [22], according to which it consists of bundles of medium and thick layers of dark gray packestones black limestones, alternating with thin and very thin layers of black calcareous mudstones with phosphate and pyrite remains, sometimes showing complete fossils of bivalves. South of Manaure reports that the La Luna Formation lies in paraconformal contact with the solid limestones and calcareous arenites of the upper part of the Cogollo Group [23], consisting basically of black calcareous mudstones in thin layers with net contacts, interstratified with bundles of layers medium dark gray limestone. Towards the upper part of the unit, the layers of calcareous mudstone and mudstone limestone become more inventive and form levels with concretions up to 1 m in diameter, with intercalations of thin layers of black chert.

Its measured thickness is 150 m, and its age according to reports from the ANH [18] is located between the Early Turonian and the Coniacian.

V. Results

A. *Petrography*

Macroscopically, the limestone samples have a massive microcrystalline appearance with few visible fossils, showing a mudstone-like texture according to the classification of AAPG [9]. However, microscopically, the limestones show a greater abundance of fossils, which is why they are actually classified as biomicrites, biopelmicrites and pelmicrites [10], [11] equivalent to wackestone and packstone [9].

They generally have an olive-gray color (code 5Y 3/2, [24]), compact, microcrystalline with massive internal structure, some with stylolite (Fig. 2C) and sparitic calcite veinlets with thicknesses ranging from 1 mm to 5 mm (Fig. 2A). They show 80% carbonated mud, 18%-20% sparitic cement and 1%-2% allochemicals. The allochemical content is distributed in 1% of intraclasts and 1% of bivalves (Fig. 2B), in some cases they were found in the same percentage (1% intraclasts and 1% bivalves); while others showed no allochemical content.

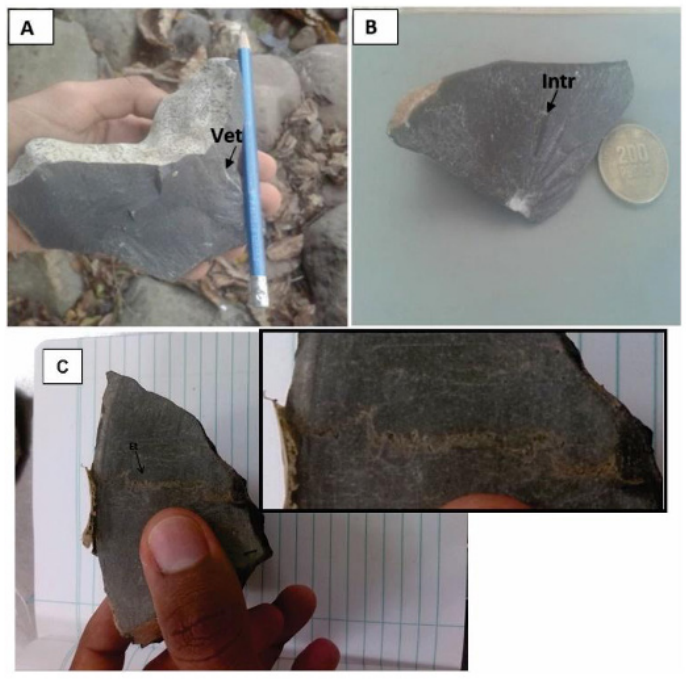

Fig. 2. Macroscopic structures. A: Calcite vein (Vet); B: Intraclast (Intr); C: Styloliths (Et).
Source: Authors.

Microscopically the samples EGZ-06, EGZ-07, EGZ-08, EGZ-09, EGZ-10, EGZ-11 and EGZ-12 show an allochemical content higher than 10% (for wackestone) and in some cases grain supported (for packstone) with carbonated sludge recrystallizing to sparite (Table 1). Samples EGZ-07 and EGZ-08 show micro veinlets of organic matter with a thickness of up to 16 µm and micro veinlets of sparite with a thickness of up to 28 µm that cut to a bivalve fragment recrystallized. They have some pellets, bivalve fragments filled with organic matter and sparite, radiolarians with a perimeter of up to 1 360 µm replaced by calcite, algae and few foraminifera of the Heterohelix moremani Cushman species recrystallized in micrite and microsparite, showing biserial shells. They present terrigenous material composed of relatively small zircon (< 0.0039 mm); iron oxide and little autogenous material in an isolated manner corresponding to glauconite with a dark greenish tonality (Fig. 3).

Table 1.
Location of collected samples

Samples	Coordinates	Lithology [9]
EGZ 06	E:1107162; N:1641512	Packstones
EGZ07	E:1107134; N:1641561	Wackestones
EGZ 08	E:1107150; N:1641521	Wackestones
EGZ 09	E:1107132; N:1641532	Wackestones
EGZ 10	E:1107114; N:1641533	Packstones
EGZ 11	E:1107172; N:1641561	Wackestones
EGZ 12	E: 1107112; N:1641582	Wackestones

Source: Authors [9].

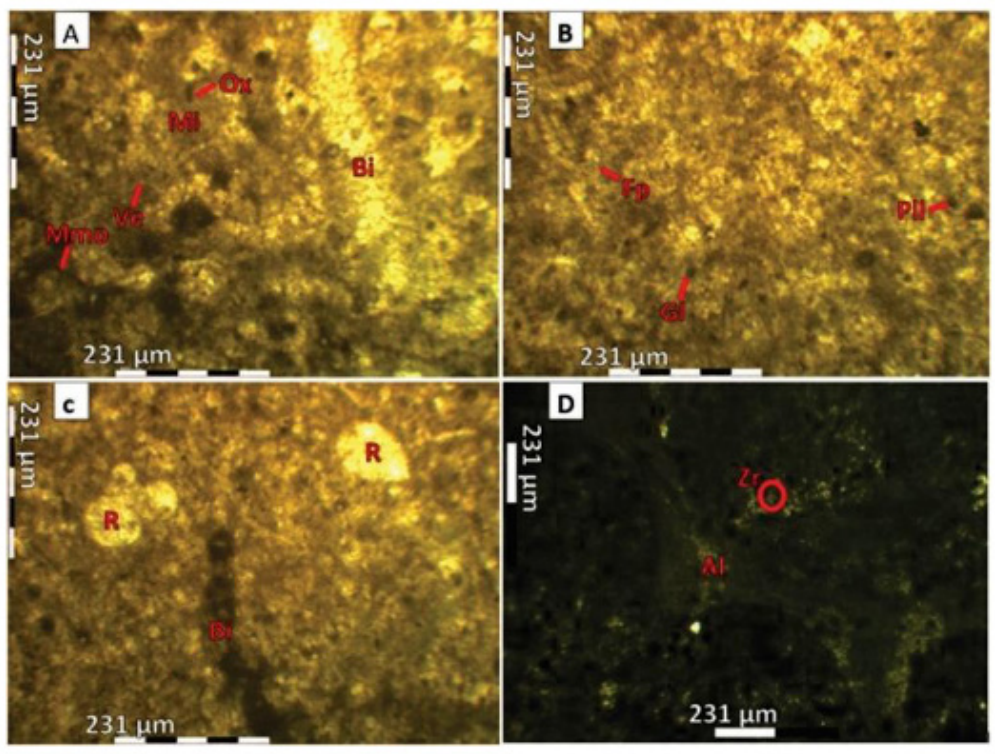

Fig. 3. Photomicrographs of thin sections belonging to samples EGZ-07 and EGZ-08. A) Bivalve recrystallized by sparite (Bi) placed in the micritic matrix (Mi), micro veinlets of organic matter (Mmo), micro veinlets of microsparite (Ve); and iron oxide (Ox). N // B) Planktonic foraminifera belonging to Heterohelix moremani Cushman (Fp), glauconite (Gl) and Pellets (Pll). N // C) Radiolaria (R) and bivalve fragments with dissolved organic matter (Bi). N // D) Alga (Al) and zircon (Zr). Nx.
Source: Authors

According to the Folk classification [10], [11], they correspond to biomicrites, and Wackestone [9].

The samples EGZ-06 and EGZ-10 have a high content of organic matter distributed throughout the matrix, presenting micro-fractures of the stylolite type of ~ 75µm located that cut into the rock, such as wavy laminations with thicknesses of ~ 37µm and reddish-brown filaments with shades dark, ~ 55µm thick, in thin and elongated shapes that differ from the micrite.

Among the bioclasts there are radiolarians with a perimeter from 671 µm to 1183 µm and mostly planktonic foraminifera of the Globigerinidae order of various genera and calciespheres, being able to identify the genus Hedbergella with a trochospiral shape and Heterohelix biseriales, observing species such as Hedbergella trocoidea Longoria. Clay-size zircon (~ 0.023mm) was found as terrigenous material and glauconite in isolation with light to pale green tonality as autogenous material (Fig. 4).

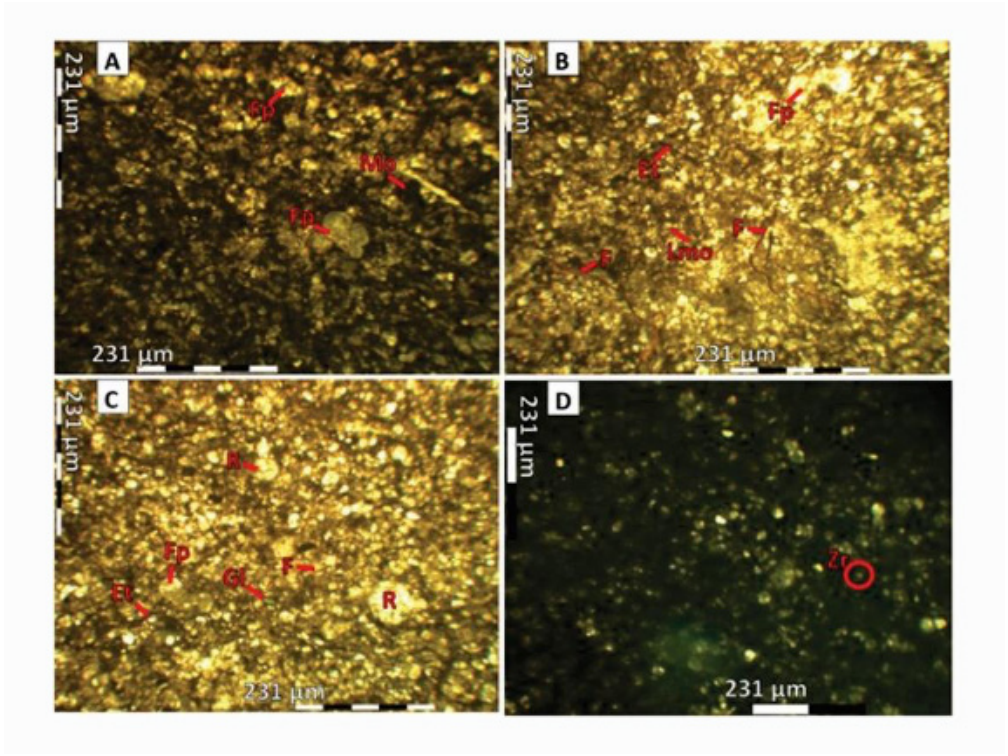

Fig. 4. Photomicrographs of thin sections belonging to samples EGZ06 and EGZ10. A) Organic matter (Mo) distributed in the matrix and planktonic foraminifera (Fp) located. N //. B) Planktonic foraminifera (Fp), filaments (F), micro-stylolite (Et) filled with organic matter and sheets of organic matter (Lmo). N //. C) Micro stylolith (Et) of organic matter, radiolaria (R) and glauconite (Gl). N // D) Zircon (Zr). Nx.
Source: Authors

According to the Folk classification [10], [11], they correspond to biomicrite, and Packstone [9].

Samples EGZ-09 and EGZ-12 show spots and bands of organic matter ~ 213 µm thick, formed by the agglutination of two or more sheets of organic matter. There are exhibited pellets, foraminifera of the globigerina order of optically radial and serial shells, algae and mainly lamellibranch and bivalve molluscs. It presents iron oxide and autogenous material composed of glauconite with a pale greenish tonality (Fig. 5).

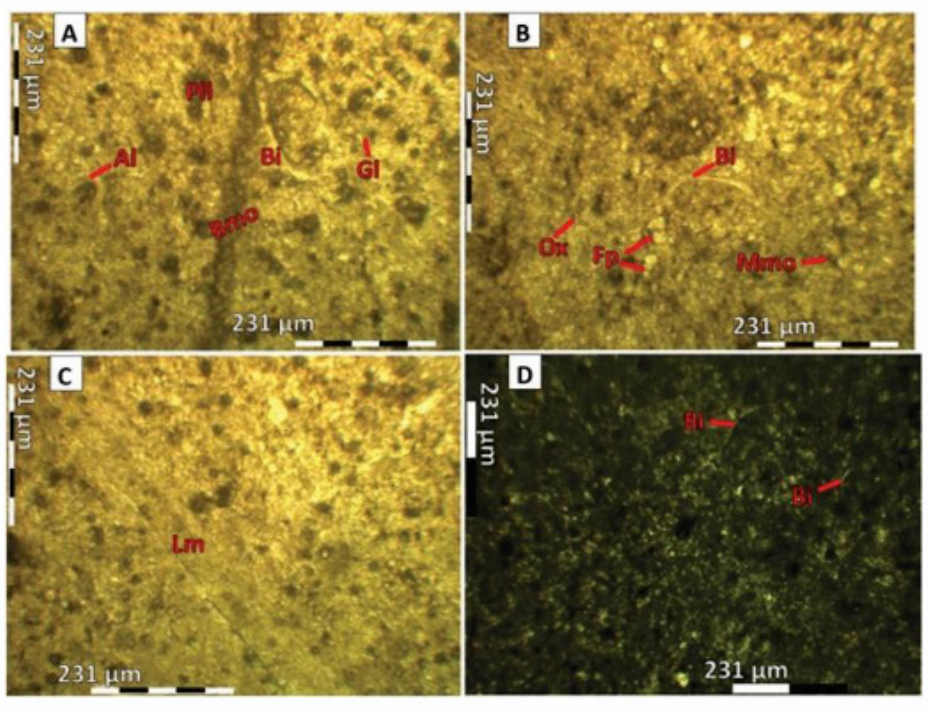

Fig. 5. Photomicrographs of thin sections belonging to samples EGZ-09 and EGZ-12. A) Band of organic matter (Bmo), Alga (Al), glauconite (Gl), pellets (Pll) and bivalve (Bi). N // B) Stain of organic matter (Mmo), bivalve (Bi) and planktonic foraminifera (Fp). N // C) Lamellibranch (Lm). N // D) Bivalves (Bi). Nx.
Source: Authors.

According to the Folk classification [10], [11] they correspond to biopelmicrite, and Wackestone [9].

Finally, sample EGZ-11 shows a large quantity of micritic peloids with a length of ~ 1117 µm; ~ 38 µm thick micro veinlets filled with sparitic calcite. They have foraminifera of the globigerinida order with globular and intraclast forms. It has iron oxide and dark greenish glauconite (Fig. 6).

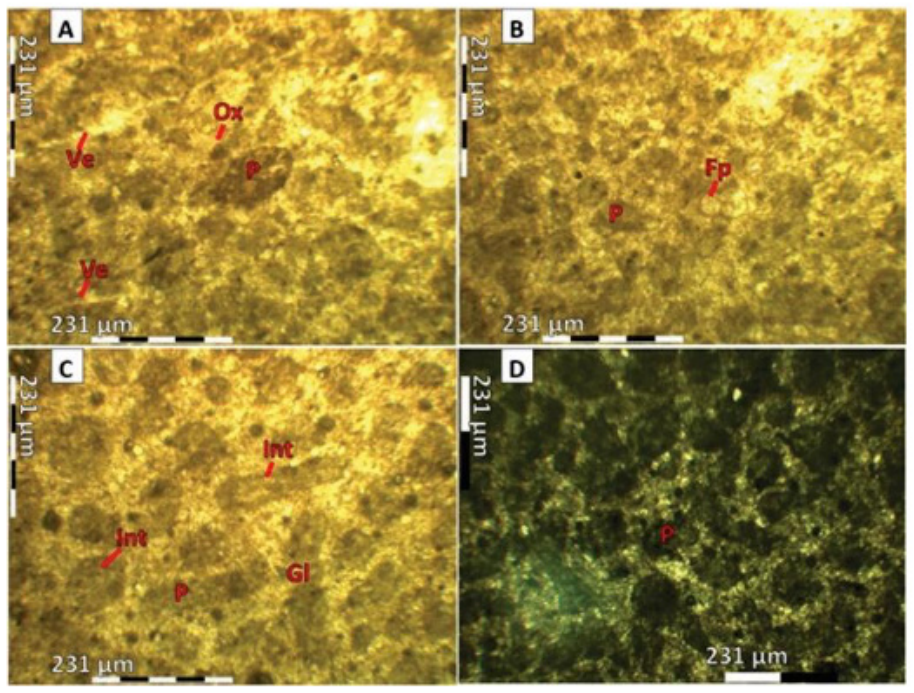

Fig. 6. Photomicrographs of the thin sections corresponding to the sample EGZ-11 A) micro veinlets of sparite (Ve), iron oxide (Ox) and peloids (P). N // B) Peloids (P) and planktonic foraminifera (Fp). N //. C) Peloids (P), intraclasts (Int) and glauconite (Gl). N //. D) Peloids (P). Nx.
Source: Authors.

According to the Folk classification [10], [11] they correspond to pelmicrites, and Wackestones [9].

B. *Stratigraphy*

The sedimentary sequence of the outcrop on the Manaure River is associated by its lithological and stratigraphic characteristics to the Lagunitas Formation of the Cogollo Group, subdivided into two segments: A and B.

4 stratigraphic sections were raised with direct measurements with Jacob's rod and sampling, measuring from stratum 1 to stratum 4 in section 1 (C1), followed by stratum 5 to stratum 21 in section 2 (C2), then stratum 22 to stratum 30 in section 3 (C3) and stratum 31 in section 4 (C4). Finally, the 4 sections were grouped and the complete stratigraphic column of the sequence was obtained (Fig. 7).

Segment A comprises section C1, C2 and C3. They correspond to the lower part of the stratigraphic column, with a partial thickness of 16.66 m, while segment B comprises section 4, upper part of the stratigraphic column, presenting a partial thickness of 5.30 m.

Segment A manifests a rhythmic sequence of tabular strata of fractured limestone and shales, exhibiting towards the base in stratigraphic section C1 a thickness of 1.38 m, in stratigraphic section C2 a thickness of 12.27 m and lastly in the stratigraphic section C3 a thickness of 3.01 m.

1) *Stratigraphic section C1*

In stratigraphic section C1, the limestones have thicknesses ranging from 43 cm to 64 cm and shales with thicknesses from 14 cm to 17 cm, with net contacts. The limestones present a karren-like exposure surface and some karst structures towards the base as a product of raindrops and water currents, have an internal olive-gray coloration (Code 5Y 3/2, [24]).

Towards the base of the section (stratum 1) the limestones present small bivalves, intraclasts and burrows as a consequence of the bivalve activity in the rock. The burrows were useful as a polarity criterion, indicating that the overlapping of the strata in the outcrop is normal, because the direction of the burrows is curve downwards.

There were intraclasts in the middle-upper part of the section (stratum 3) found.

Shales have a planar horizontal laminar structure, with an internal coloration equivalent to moderate greenish yellow (Code 10Y 7/4, [24]) and dark yellow green (Code 5GY 5/2, [24]). They are composed of clays and silts.

2) *Stratigraphic section C2*

The limestones have a thickness of 18 cm to 2.68 m and shales with a thickness of 8 cm to 37 cm, with a net contact between each stratum. The limestones present a massive exposure surface, with an internal color variation equivalent to grayish olive green (Code 5GY 3/2, Rock-color chart: With genuine Munsell color chips. Grand Rapids [24]) in stratum 7, green dark yellow (Code 5GY 5/2, [24]) in stratum 9 and olive gray in the other strata (Code 5Y 3/2, [24]).

Small calcite veinlets were found in stratum 5, 7, 9, 13, and 15, intraclasts in stratum 17 and 21, small bivalves in stratum 5, 7, 11, 13, 19 and 21 and ichnofossils of shells in Stratum 11. Burrows produced by bivalves and horizontal stylolites filled with carbonaceous mud material also exhibited in the lower part of the section (stratum 5).

Shales presents a planar horizontal laminar structure, with an internal coloration equivalent to moderate greenish yellow (Code 10Y 7/4, [24]), dark yellow green (Code 5GY 5/2, [24]), pale yellowish green (code 10GY 7/2 [24]), pale green and blue-gray green (code 5G 7/2 & 5BG 5/2, [24]. These are with a compositional balance of clay and carbonaceous silt.

In most of these strata, there are massive carbonate nodules (stratum 10, 12, 14, 18 and 20) with globular or ellipsoidal shape.

3) *Stratigraphic section C3*

Consisting of limestone with a thickness of 21 cm to 1.53 m and shales with a thickness of 1 cm to 20 cm, with net contact between each stratum, except for stratum 26, which has a lower gradational contact. The limestones have a massive exposure surface, with an internal coloration equivalent to grayish olive green and olive gray (Code 5GY 3/2 & 5Y 3/2, [24]). They present veinlets filled with calcite in the lower and upper part of the section (stratum 23 and 27), intraclasts (stratum 27 and 29) and bivalves (stratum 29) in the upper part.

Shales have a planar horizontal laminar structure, with a coloration equivalent to grayish-yellow green (Code 5GY 7/2, [24]) and pale yellowish green (code 10GY 7/2, [24]). They are composed of a balance of clays and silts.

Segment B is characterized by manifesting itself as a homogeneous sequence of limestone with multiple fractures, overlying segment A in net contact, and with a geometric relationship parallel to the strata of segment A.

4) *Stratigraphic section C4*

Stratigraphic section C4 has a thickness of 5.30 m, so it is equivalent to the partial thickness of segment B or the thickness of the limestone stratum. This is found with an internal coloration equivalent to olive gray (Code 5Y 3/2, [24]), with a massive structure and some karst processes with the generation of caves and galleries. The gallery presents a semi-horizontal conduit originated by the widening of cracks and joints, due to the dissolution of the rock. The rock has small bivalves; some veinlets filled with carbonates and expels the smell of gas when fractured.

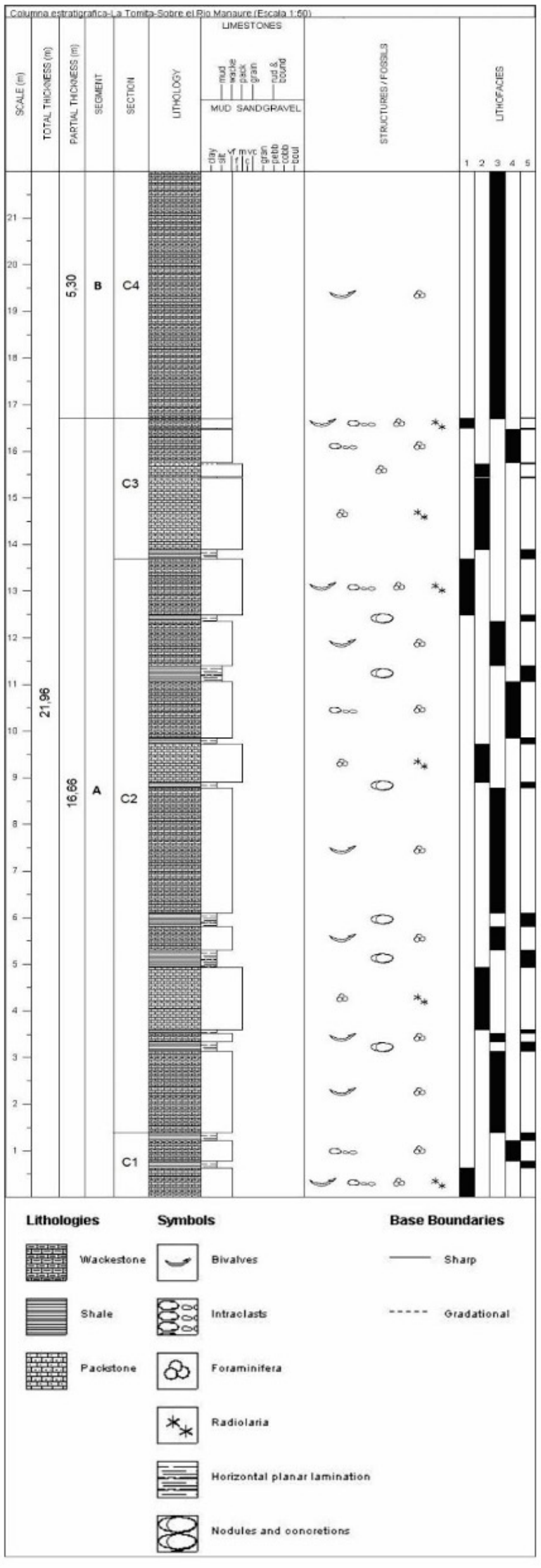

Fig. 7. Stratigraphic column - La Tomita - On the Manaure River. Scale 1:50.
Source: Authors.

C. *Facies analysis*

The outcrop of the Lagunitas Formation presents 5 lithofacies, which are divided into carbonate facies and mixed facies

1) *Carbonated facies*

Lithofacies 1. Wackestones with pelagic microfossils: Made up of pelagic foraminifera (globigerinids), some bivalves, pellets, radiolaria, and a few algae immersed in a micrite matrix. Radiolaria contain sparite, foraminifera micritized, bivalves fragmented, disarticulated and recrystallized mostly by sparite.

Within these facies are the samples EGZ07, EGZ08 (Fig. 3); in the stratigraphic column, the limestones were associated with bivalves and intraclasts at the macroscopic level. These lithofacies correspond to a standard microface type 3 (SMF 3) [25], and a ramp type 5 (RMF 5) [26].

Lithofacies 2. Bioclastic packstones: Made up of various globigerinoid foraminifera bioclasts and some radiolaria recrystallized in sparite and micrite: Within these facies are the samples EGZ06, EG10 (Fig. 4); in the stratigraphic column they were associated with totally massive or microcrystalline limestones. They are equivalent to a standard microface type 9 (SMF 9) [25], and a ramp type 5 (RMF 5) [26].

Lithofacies 3. Wackestones with worn mollusc bioclasts: It is mainly made up of bivalves, lamellibranchs, globigerinid foraminifera and pellets, in a muddy matrix.

Bivalves are fragmented, disarticulated and recrystallized by sparite and micrite. Foraminifera are highly micritized.

Within these facies are the samples EGZ09, EGZ12 (Fig. 5); in the stratigraphic column, the limestones were associated with bivalves at the macroscopic level. This lithofacies is equivalent to a standard microface type 10 (SMF 10) [25], and a ramp type 7 (SMF 7) [26].

Lithofacies 4. Wackestones with peloids: Mainly constituted by micritic peloids and small globigerinid foraminifera and intraclast bioclasts.

The peloids have a rounded to ellipsoidal shape and the foraminifera appear micritized.

Within this, facies are the sample EGZ11 (Fig. 6), in the stratigraphic column, the limestones were associated with macroscopic intraclasts. This lithofacies is equivalent to a standard microfacies type 2 (SMF 2) [25], and a ramp type 4 (RMF 4) [26].

2) *Mixed facies and lithofacies*

Mudstone shales: It corresponds to laminar and fine-grained lithified shales (mud size), composed mainly of an intermediate percentage of carbonate clays and silts. These are equivalent to the textural class 'M' within the triangular diagram for the textural classification of fine-grained terrigenous rocks [27] with 60% in clays and 40% in silts. In the stratigraphic column, all laminar shales were associated.

According to the stratigraphic column of the La Tomita outcrop located on the Manaure River (Fig. 7), lithofacies are distributed as follows:

Stratigraphic section 1 (C1): Consisting of wackestones with pelagic microfossils and wackestones with peloids separated by shale mudstones.

Stratigraphic section 2 (C2): Made up mostly of wackestones with worn mollusc bioclasts and some bioclastic packstones separated by shale mudstones towards the middle and lower parts; While in the upper part it is made up of wackestones with pelagic microfossils, wackestones with worn mollusc bioclasts and wackestones with peloids separated by shales mudstones.

Stratigraphic section 3 (C3): Constituted towards the lower part by bioclastic packstones separated by shales mudstones and towards the upper part by wackestones with pelagic microfossils and wackestones with peloids separated by shales mudstones

Stratigraphic section 4 (C4): Made up of wackestones with worn mollusc bioclasts.

D. *Depositional environment analysis*

Taking into account the facial characteristics of the carbonate rocks in the study area, the environmental facial associations described [25], [26] them are presented, as follow:

1) *Facial association 1*

The calcareous rocks of segment A developed in an environment with a change in energy level in an open sea rich in carbonates and a relative abundance of organic matter. This is evidenced by the fragmentation, disarticulation and distribution of some fossils such as bivalves, indicating intermittent episodes of storms, being characteristic of high or moderate energy environments, but preserving the calcareous mud [28]. Radiolarians, some fossils preserved although replaced by micrite and sparite, ichnofossils and burrows indicate water events rarely reworked by storms, which are characteristic of environments with low energy [7], [26], [28].

The low presence of terrigenous material suggests broad platforms with very gentle slopes, as evidenced by some calcareous marine algae [7], [29].

The facial area is corroborated by the presence of planktonic foraminifera, which require open marine conditions [30].

2) *Facial association 2*

The framework of segment B indicates depositional environments with high or moderate energy rich in carbonates and organic matter (but conserving the muddy matrix), reflected by the fragmentation, disarticulation and distribution of a large part of the bioclasts [28]. Like facial association 1, the low presence of terrigenous material suggests wide platforms with very gentle slopes [7], and open sea conditions, which is evidenced by planktonic foraminifera [30].

Among other characteristics are the filaments that are associated with microbial activity [31], and organic matter as a result of planktonic organisms that accumulate when they die and are subsequently buried [32]. According to several authors [33], there is evidence that in some oceanic environments organic matter consists of a mixture of autochthonous compounds and, to a lesser extent, of terrestrial origin that have been transported through various mechanisms.

VI . Conclusions

In the village of La Tomita, in the Municipality of Manaure (Cesar, Colombia), the stratigraphic outcrops of biomicritic, biopelmicritic, pelmicritic limestones, interspersed with shales, belong to the Lagunita Formation of the Cogollo Group.

The limestones present a massive structure, some veinlets of calcite, organic matter, various fossils belonging to bivalves, foraminifera, intraclasts, pellets, peloids, some radiolaria and algae. There were among the foraminifera, species corresponding to Heterohelix moremani Cushman and Hedbergella trocoidea Longoria.

Mineralogically, within its orthochemical components it is composed of micritic mud and sparite, with a fossil content greater than 10% as allochemical components, which are in some rocks with a matrix-supported skeleton, while in other rocks they are in a grained-supported skeleton. Within the terrigenous elements, only clay-sized zircons were identified and, in their autogenic or diagenetic elements, only glauconites.

A planar horizontal laminar structure and present microcrystalline carbonate nodules in some strata characterize shales. Compositionally they reveal a balance of carbonated clays and silts.

Four lithofacies were determined for limestones, called carbonate rock facies, and one lithofacies for shales called mixed rock facies. The limestones correspond to a lithofacies of wackestone with pelagic microfossils, bioclastic packstone, wackestone with worn mollusc bioclasts and wackestone with peloids, while the shales correspond to mudstones shales.

The depositional environment is as a middle platform with some external platform intervals encompassing an open ocean facies zone rich in carbonates and organic matter.

References

[1] G. de los Reyes, Z. Mendoza, E. Mosquera, E. Rojas, D. Manco y F. Lascarro, "Geoquímica de las calizas del sector La Tomita, municipio de Manaure-Cesar. Aporte a la determinación de su uso como material industrial," *Prospect*, vol. 18, no. 2, pp. 1–14, Ago. 2020. Available: http://ojs.uac.edu.co/index.php/prospectiva/article/view/2192

[2] D. Manco, C. Robles y E. Rojas, "Descripción de los impactos ambientales causados por el inadecuado manejo en la caverna sabana de león y cueva coco loco, municipio de Manaure, Serranía de Perijá, departamento del Cesar-Colombia," *Ingeniare*, no. 23, pp. 25–34, Sep. 2017. https://doi.org/10.18041/1909-2458/ingeniare.2.2881

[3] F. Colmenares, A. Mesa, J. Roncancio, E. Arciniegas, P. Pedraza, A. Cardona, A. Romero, C. Silva, S. Alvarado, O. Romero y A. Vargas, *Geología de las planchas 11, 12, 13, 14, 18, 19, 20, 21, 25, 26, 27, 33, 34 y 40. Proyecto: Evolución geo histórica de la Sierra Nevada de Santa Marta*. BO, CO: Ingeominas, 2007. Recuperado de https://recordcenter.sgc.gov.co/B12/23008010018162/documento/pdf/2105181621101000.pdf

[4] L. Haught, B. Colley & H. Belding, "Geology of the Cesar-Rancheria Valley and commissary of Guajira," Tropical Oil Company, BO, CO, *Geological Report*, unpublished, 1945.

[5] R. Ayala, "Análisis tectonoestratigráfico y de procedencia en la Subcuenca de Cesar: relación con los sistemas petroleros," *MSc. Tesis*, USB, Sarten, VE, 2009.

[6] SGC-Gemi, H. González, R. Salinas, J. Cárdenas, C. Muñoz, y W. Vélez, "Elaboración de la cartografía geológica de un conjunto de planchas a escala 1:100.000 ubicadas en cuatro bloques del territorio nacional, identificados por el Servicio Geológico Colombiano", SGC, MED, CO, *Plancha 41-Becerril. Memoria Explicativa*, 2015. Recuperado de https://recordcenter.sgc.gov.co/B15/23008010028468/Documento/Pdf/2105284681101000.pdf

[7] Geoestudios Limitada, "Cartografía geológica y muestreo en tres áreas de Colombia: Santander, Tolima y Cesar", Geoestudios Limitada, BO, CO, *Informe*, 2014.

[8] F. Etayo, "Metodología de trabajo del proyecto cretácico," *Ingeominas*, no. 16, Especial, pp. 1–13, 1985. Disponible en https://cata4logo.sgc.gov.co/cgi-bin/koha/opac-detail.pl?biblionumber=12338&shelfbrowse_itemnumber=122442#holdings

[9] R. J. Dunham, "Classification of Carbonate Rocks According to Depositional Texture" in *Classification of Carbonate Rocks-A Symposium*, TLS, OK: AAPG, 1962, pp. 108–121. https://doi.org/10.1306/M1357

[10] R. L. Folk, "Spectral Subdivision of Limestones Types," in: W. E. Ham, Ed., *Classification of Carbonates Rocks. A Symposium*, Tulsa, OK, USA, AAPG Memoirs, 1962, pp. 62-84. https://doi.org/10.1306/M1357

[11] R. L. Folk, "Practical Petrographic Classification of Limestones," *AAPG Bulletin*, vol. 43, no. 1, pp. 1–38, Jan. 1959. https://doi.org/10.1306/0BDA5C36-16BD-11D7-8645000102C1865D

[12] A. Taboada, L. Rivera, A. Fuenzalida, A. Cisternas, H. Philip, H. Bijwaard, J. Olaya & C. Rivera, "Geodynamics of the northern Andes: Subductions and intracontinental deformation (Colombia)," *Tectonics*, vol. 19, no. 5, pp. 787–813, Oct. 2000. https://doi.org/10.1029/2000TC900004

[13] D. Manco, E. Rojas y B. Gomez, "Estudio petrográfico del yacimiento de caliza presente en el municipio de la Paz, departamento del Cesar," *Prospect*, vol. 12, no. 2, pp. 82–89, Dic. 2014. http://dx.doi.org/10.15665/rp.v12i2.292

[14] Ingeominas, F. Buchely, L. Gómez, J. Lancheros, C. Dávila, C. López, O. Romero, F. González, J. Fuquen y O. Navas, *Cartografía geológica y muestreo geoquímico de la parte norte de la Serranía de Perijá Planchas 21, 22, 27, 28, 34 y 35*. BO, CO: SGC, 2010. Dispopnible en https://catalogo.sgc.gov.co/cgi-bin/koha/opac-detail.pl?biblionumber=49000&shelfbrowse_itemnumber=79410

[15] O. Rivera y J. Fernández, "Análisis corológico de la flora endémica de la Serranía de Perijá, Colombia", *Anales Jard Bot Madrid*, vol. 60, no. 2, pp. 347–369, Jul. 2003. Disponible en http://hdl.handle.net/10261/32622

[16] J. B. Miller, "Memoria. Directrices tectónicas en la sierra de Perijá y partes adyacentes de Venezuela y Colombia", presentado al *III Congreso Geológico Venezolano*, CCS, CAR, VE, 1960. Disponible en https://catalogo.sgc.gov.co/cgi-bin/koha/opac-detail.pl?biblionumber=13053

[17] E. Castro, "Aspectos geológicos y principales consideraciones de la evaluación ambiental estratégica (diagnóstico ambiental) del distrito minero La Jagua, departamento del Cesar", *Monografia, Esp. Ing. Amb.*, UIS, BGA, CO, 2009. Disponible en https://kipdf.com/emerson-castro-sanchez_5afdefc18ead0e963a8b4668.html

[18] M. Garcia, R. Mier, A. Arias, Y. Cortes, M. Moreno, O. Salazar y M. Jiménez, "Prospectividad de la Cuenca Cesar Ranchería", ANH, BO, CO, *Informe*, 2008. Recuperado de https://www.anh.gov.co/documents/4164/Cesar_Rancheria.pdf

[19] M. Hernández, "Geología de las planchas 11 Santa Marta y 18 Ciénaga", Ingeominas, BCA, CO, *Informe*, 1996. Recuperado de https://recordcenter.sgc.gov.co/B4/13010010024387/Documento/pdf/0101243871102000.pdf

[20] M. Lozada, F. Lascarro, L. León, E. Rojas, F. Carrillo, L. Tapia y D. Manco, "Contribución al conocimiento geológico de la Serranía del Perijá mediante cartografía a escala 1:25.000 del Grupo Cogollo, en el sector oriental del municipio de Becerril, Cesar", *Bol geol*, no. 45, pp. 49–59, Jul. 2019. https://doi.org/10.32685/0120-1425/boletingeo.45.2019.487

[21] H. Cáceres, R. Camacho & J. Reyes, "The geology of the Ranchería Basin," presented at *19th Field Conference*, FC, BO, CO, 1980. Available: https://www.acggp.org/field-trips/

[22] A. H. Garner, "General Oil Geology of Colombia," *AAPG Bull*, vol. 11, no. 2, pp. 151–156, Feb. 1927. https://doi.org/10.1306/3D932772-16B1-11D7-8645000102C1865D

[23] M. García, L. Cruz, R. Mier, M. Vásquez, M. Jiménez y M. Moreno, "Evolución térmica de la Subcuenca de la Baja Guajira", ANH, BO, CO, *Informe Final*, 2010. Available from https://www.anh.gov.co/documents/2736/Evolucion_Termica_de_la_Baja_Guajira.pdf
[24] GSA, AAPG, SEG & AASG, *Geological Rock-color chart with genuine Munsell color chips*. GRR, MI: Munsell Colors, 2009. Available: https://www.studocu.com/ec/document/universidad-ute/geologia-ambiental/geological-rock-color-chart-1/19254177
[25] J. L. Wilson, *Carbonate Facies in Geologic History*. NYC, NY: SSE, 1975. Available: https://link.springer.com/book/10.1007/978-1-4612-6383-8
[26] E. Flügel, *Microfacies of Carbonate Rocks Analysis, Interpretation and Application*. BE, DE: Springer-Verlag, 2004. Available: https://link.springer.com/book/10.1007/978-3-642-03796-2
[27] R. L. Folk, *Petrology of Sedimentary Rocks*. ATX, TX: Hemphill Pub Co, 1980. Available: http://hdl.handle.net/2152/22930
[28] D. A. Kietzmann, R. M. Palma & G. S. Bressan, "Facies y microfacies de la rampa tithoniana-berriasiana de la Cuenca Neuquina (Formación Vaca Muerta) en la sección del arroyo Loncoche-Malargüe, provincia de Mendoza", *RevAsoc Geol Arg*, vol. 63, no. 4, pp. 696–713, Dic. 2008. Available: http://hdl.handle.net/11336/93175
[29] M. Hernández, "Geología de Plancha 48-La Jagua de Ibirico, escala 1:100.000", Ingeominas, BGA, CO, *Memoria Explicativa*, 2000. Recuperado de https://recordcenter.sgc.gov.co/B4/13010010020444/documento/PDF/0101204441102000.pdf
[30] H. Camacho y M. Longobucco, *Los invertebrados fósiles*. CABA, AR: Vásquez Mazzini Editores, 2007. Recuperado de https://www.fundacionazara.org.ar/img/libros/invertebrados-fosiles-I.pdf
[31] J. Schieber, "Microbial mats in terrigenous clastics; the challenge of identification in the rock record," *Palaios*, vol. 14, no. 1, pp. 3–12, Feb. 1999. https://doi.org/10.2307/3515357
[32] L. Pichevin, P. Bertrand, M. Boussafir & J. Disnar, "Organic matter accumulation and preservation controls in a deep sea modern environment: an example from Namibian slope sediments," *Org. Geochem.*, vol. 35, no. 5, pp. 543–559, May. 2004. https://doi.org/10.1016/j.orggeochem.2004.01.018
[33] A. Blanco-Piñon, F. Maurrasse, F. Zavala-Diaz de la Serna, R. Lopez-Doncel, S. Angeles-Trigueros, J. Hernandez y E. Juarez, "Evidencias petrográficas de estructuras de origen algal/bacteriano en carbonatos de la Formación Agua Nueva (Cenomaniano/Turoniano: Cretácico Superior) en Xilitla, S.L.P. México central," *Bol Soc Geol Mex*, vol. 66, no. 2, pp. 397–412, Ago. 2014. https://doi.org/10.18268/BSGM2014v66n2a13

Génesis Carolina De Los Reyes Díaz. Fundación Universitaria del Área Andina (Colombia). https://orcid.org/0000-0002-7383-073X

Zamir Mendoza Mejía. Fundación Universitaria del Área Andina (Colombia). https://orcid.org/0000-0002-8160-4046

Eloy I. Mosquera Nieves. Fundación Universitaria del Área Andina (Colombia). https://orcid.org/0000-0002-6906-4729

Elías Ernesto Rojas Martínez. Fundación Universitaria del Área Andina (Colombia). https://orcid.org/0000-0003-0402-1565

Dino Carmelo Manco Jaraba. Universidad de La Guajira (Colombia). https://orcid.org/0000-0001-8506-094X

Frank Lascarro Navarro. Universidad Mayor de San Marcos (Perú). https://orcid.org/0000-0001-9433-2863