Boletín Geológico

Boletín Geológico, 50(1), 2023
https://doi.org/10.32685/0120-1425/bol.geol.50.1.2023.689

Received: December 16, 2022
Revision received: May 23, 2023
Accepted: May 31, 2023
Published online: June, 19, 2023

Review article

Revisiting the latest Jurassic-earliest Cretaceous Los Santos Formation, Eastern Cordillera of Colombia. A – The history of its origin and the lowermost part of the unit

Revisitando la Formación Los Santos - Jurásico tardío a Cretácico temprano, Cordillera Oriental de Colombia. A - La historia de su origen y la parte más inferior de la unidad

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ABSTRACT
A historical account is made of the way in which various researchers have conceptualized the regional geological framework and local exposure of a lithostratigraphic unit spanning from latest Jurassic to early Cretaceous, widely distributed in the Mesas and Cuestas region of the Eastern Cordillera of Colombia. In this first part of the revisit exercise of the Los Santos Formation, the lowermost part of the unit is analyzed, the development of its lithofacies from a detailed definition performed in the type section and its correlation with eleven additional stratigraphic sections. From this analysis, four main lithofacies with an important gravel-size quartz -quartzite content is determined east of the Suárez fault - south of the Los Montes transverse fault, while north of the area in the vicinity of the Lebrija and Solferino faults, the rudite fraction is almost entirely made up of brownish red sedimentary clasts. To the west of the Suarez fault-south of the Sogamoso fault, intercalated sandstones and shales predominate. A trend of sedimentological development is observed in all the stratigraphic columns with gravel-size contribution, from polymodal conglomerates, disordered fabric, poorly calibrated and supported by matrix to well-bedded intercalations of conglomerates, sandstones and shales. A structural control in the sedimentation is deduced, which is reflected in the shape, thickness and occurrence of the investigated facies and related faults.

Keywords: Mesas and Cuestas; revisit; facies; tectonic response; Suarez

Citation: Laverde-Montaño, F. (2023). Revisiting the latest Jurassic-earliest Cretaceous Los Santos Formation, Eastern Cordillera of Colombia. A – The history of its origin and the lowermost part of the unit. Boletín Geológico, 50(1). https://doi.org/10.32685/0120-1425/bol.geol.50.1.2023.689

RESUMEN

Se hace un recuento histórico de la forma en que diversos investigadores han conceptualizado el marco geológico regional y la exposición local de una unidad litoestratigráfica que abarca desde el Jurásico tardío hasta el Cretácico temprano, ampliamente distribuida en la región de Mesas y Cuestas de la Cordillera Oriental de Colombia. En esta primera parte del ejercicio de revisita de la Formación Los Santos, se analiza la parte más baja de la unidad, el desarrollo de sus litofacies a partir de una definición detallada realizada en la sección tipo y su correlación con once secciones estratigráficas adicionales. A partir de este análisis se determinan cuatro litofacies principales tamaño grava con un importante contenido de cuarzo-cuarcita al este de la falla Suárez - al sur de la falla transversal Los Montes, mientras que al norte del área en las cercanías de las fallas de Lebrija y Solferino la fracción rudítica está compuesta casi en su totalidad por clastos sedimentarios rojos. Al oeste de la falla de Suárez-sur de la falla de Sogamoso predominan las areniscas y lutitas intercaladas. Se observa una tendencia de desarrollo sedimentológico en todas las columnas estratigráficas con aporte tamaño grava, desde conglomerados polimodales, de estructura desordenada, mal calibrados y soportados por matriz hasta intercalaciones bien estratificadas de conglomerados, areniscas y lutitas. Se deduce un control estructural en la sedimentación, que se refleja en la forma, espesor y ocurrencia de las facies investigadas y fallas relacionadas.

Palabras clave: Región de Mesas y Cuestas; revisita; facies; respuesta tectónica; falla del Suarez

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1. Introduction

After several years of having participated as a geologist in the activities carried out by a group of professionals in the "Cretaceous Project" under the direction of Dr. Fernando Etayo-Serna, whose publication dates back to 1985, I have been invited by a couple of colleagues who were members of the aforementioned project, to participate in the development of the survey and interpretation of a stratigraphic section of the Los Santos Formation on the road that leads from the town of Zapatoca to the Platanalito mine, Eastern Cordillera of Colombia (this contribution is now in progress). This activity of returning to the field and observing from a different point of view, based on the experiences gathered during past years, has not only allowed to share and discuss other possibilities with my colleagues, but also to delve once again into the problems of this lithostratigraphic unit in other sectors of the Mesas and Cuestas Region-Eastern Cordillera of Colombia. See Figure 1 (a), Figure 1 (b).

That is why, I have continued with the understanding of the lowermost part of the Los Santos Formation ("Revisiting the Los Santos Formation -Part A"- this paper), and the review of the stratigraphic sections surveyed by the members of the aforementioned Cretaceous project and I have supplemented them with some new data ("Revisiting the Los Santos Formation-Part B"). All of these efforts have attempted to integrate local and regional aspects of this unit. The lithologies that make up the Los Santos Formation are exposed along roads, trails, streams, and in good panoramic views of the mountainous region of Las Mesas and Cuestas in the Cordillera Oriental of Colombia. These exposures are oriented parallel, perpendicular and oblique to the depositional dip. These outcrops, therefore, provide important data that, when correlated, allow an understanding of the development of this unit in the regional geological framework.

The main objectives of this article are: (i) to review the contributions of researchers on this topic to currently understand the points in favor and the controversial ones about the meaning of the Los Santos Formation in the Mesas and Cuestas area. (ii) to describe sedimentological and integrate the information of the basal succession of the Los Santos Formation, which is the one issue that presents the most controversy.

2. Geological setting- A long and controversial history

The first reference about geological aspects of the area is that of Hettner (1891), when he defines the "Estratos or Piso de Giron" to a succession of sandstones, red mudstones and limestones outcropping between Zapatoca and Giron, assigning them a Lower Cretaceous age without a paleontological base (Table 1).

Notestein (*in* Schuchert, 1935) affirms that the Cretaceous of the Mesa de Los Santos is found to be unconformable over pre-Cretaceous red bed lithologies, while Oppenheim (1940) considers this unconformity to be of a local character, assigning a Jurassic age for the Giron Formation by correlating it with the La Quinta Formation of Venezuela. Dickey (1941) states that the lower limit of the Giron Formation is concordant with the Bocas Series and the upper limit is paraconformable with the Rosablanca Formation. Trumpy (1943) thinks that the Giron Formation is of Upper Triassic age and is made up solely of sandstones, conglomerates, red and green shales with good exposure in the Lebrija River gorge. An important stratigraphic and structural framework and understanding of the area is due to the pioneering work of Julivert (1958 a, b; Julivert, 1959; Julivert, 1961; and Julivert, 1963) - see Table 2.

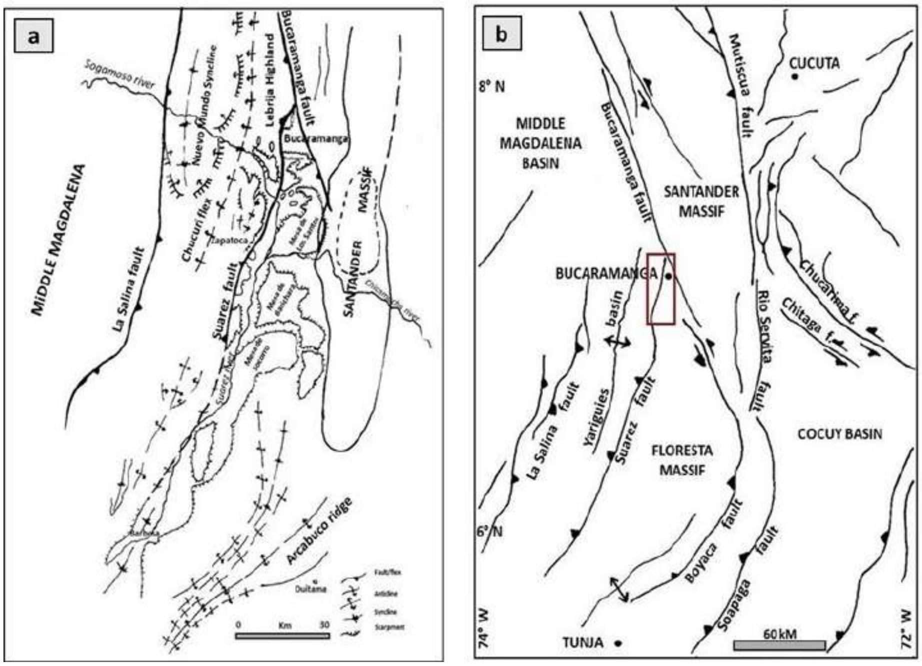

Figure 1. Location of the study area. (a) Main geological features of the Mesas and Cuestas region. Map redrawn from Julivert, 1963. (b). Main structural elements of the Eastern Cordillera north of Tunja, by Forero-Ortega et al., 2020. In the red square the work area.

Table 1: Stratigraphic nomenclature of the Los Santos Formation and associated units.

Authors	Localities	Paleozoic	Triassic	Early Jurassic	Middle Jurassic	Late Jurassic		Early Cretaceous	
Hettner,1891	Giron-Zapatoca area							Piso de Giron	
Schuchert, 1935	West of Bucaramanga		Red beds					Cretaceous sediments	
Oppenheim, 1940	Bucaramanga & Mesas		Giron Formation						
Dickey, 1941	Bucaramanga & Mesas	Bocas series	Giron Formation					Rosablanca	
Trumpy, 1943	Lebrija river gorge		Giron Fm.						
Morales et al, 1958	Magdalena basin		Giron Formation .				Tambor Fm.	Rosablanca Fm.	
Julivert, 1958 a, b	Mesas region	Igneous and metamorphic basement	Giron Formation					Tambor Fm.	Rosablanca Fm.
Langenheim, 1959	Lebrija area	Carboniferous crystalline rocks	Giron Formation .					Tambor Fm.	Marine Cretaceous
Navas, 1963	Lebrija river gorge	Crystalline/Bocas	Giron Formation				U.C	Tambor Fm.	Rosablanca Fm.
Cediel, 1968	Lebrija river gorge	Bocas Fm.	Jordan Fm.	Giron Formation			R.C	Los Santos Fm.	Rosablanca Fm.
Etayo-Serna, 1989	Lebrija river gorge			Angostura del rio Lebrija Formation			T.M	Los Santos Fm.	Cumbre, Rosablanca Fms.
Horton et al, 2015	Los Yariguíes anticlinorium		Bocas Fm.	Jordan Fm		Angostura del rio Lebrija Fm.		Los Santos Fm.	Rosablanca Fm.
Moreno-Sanchez, 2019	Sogamoso river and Zapatoca area					Giron Group		Los Santos Fm.	Cumbre, Rosablanca Fms.
Etayo-Serna and Guzman, 2019	Sogamoso river and Zapatoca area							Los Santos Fm.	Cumbre, Rosablanca Fms.
Alarcon and Rodriguez, 2019	Mesa de Los Santos		Bocas Fm.	Jordan Fm.				Los Santos Fm	
Jiménez et al 2021	Los Yariguíes anticlinorium					Angostura del rio Lebrija Fm.	Los Santos Formation		Cumbre Rosablanca
Laverde this work	Mesa de Los Santos and Yariguíes					Rio Lebrija Formation	Los Santos Formation		Cumbre, Rosablanca Fms.
		U.C: Upper Conglomerate of Giron Fm; R.C: Red Conglomerate of the Giron Fm; T.M: Tambor Member of the Angostura del rio Lebrija Fm.							

Table 2: Main ideas about the stratigraphic and structural framework of the Mesas and Cuestas region outlined by Julivert (1958 a, b; 1959, 1961 and 1963).

The Mesas and Cuestas Region is limited by two major structural accidents: The Chucuri Flexion to the west and the Bucaramanga fault to the east. Another feature that longitudinally divides the Mesas and Cuestas Region is the Suarez Fault, striking N-S. This fault divides the Mesas Region into two structural units of the second order: a western one formed by the Lebrija Highland and the Zapatoca Massif, and an eastern one comprising Bucaramanga, the Mesa de Ruitoque, the Mesa de Los Santos, and the area of Barichara-Curiti-San Gil. In that area, a set of faults or bends are oriented approximately N-S; all these accidents are structural features controlled by the basement on which the Mesozoic pile of sediments adapts, forming a flexion or coming to break to give place to faults
Main components of the Mesas and Cuestas region are a package of Cretaceous strata overlying the Triassic-Jurassic rocks, which are resting on an igneous-metamorphic basement. The common structural characteristic of the Mesas and Cuestas Region (Ruitoque, Los Santos and Barichara) is the general dip to the west in both the sedimentites of the Cretaceous successions and the underlying Triassic-Jurassic rockbodies..
Pre-Cretaceous erosion beveled the Jurassic units tilted to the west, and this important geologic feature is the cause of the absence or lower thicknesses of the Jurassic rock bodies to the east. Consequently, Julivert thinks that the Jurassic and older units are unconformably cut by an important erosional event. After this event occurs a deposition of the Cretaceous siliciclastics, causing that this succession covers it transgressively.
Transgressive facies begins with a basal sandstone with levels of conglomerate, whose age depending on the transgression advance, is progressively modern towards the N (upper Jurassic in a region located southward –known as Arcabuco, and lower Hauterivian in the Mesa de Los Santos). The potency of the succession also decreases from S to N. Another characteristic identified from the Lower Cretaceous is the increase of sandy facies toward the East.
Recognition of three main erosion surfaces in the region: a pre-Mesozoic, on which the Triassic-Jurassic red beds sequences rests, another pre-Cretaceous and post-Jurassic surface that cuts Jurassic units in a beveled way and serves as the base for the deposition of the Cretaceous sandstones, and the third one, the Pliocene erosional surface. He concluded that the character of marine sedimentation develops from the sandy level that forms the base of the Cretaceous and continues throughout this period.

Morales *et al*. (1958) based on an unpublished report by Hedberg (1931) named a lithostratigraphic unit composed by sandstones and interbedded red shales of the Upper Jurassic to Lower Cretaceous age, which is widely exposed in the Mesas and Cuestas region, as equivalent to the local exposure of conglomerates composed of clayey rocks and fine-grained red sandstones present in the Bocas-Conchal area, termed as the Tambor Formation by Hedberg (*op. cit*). Additionally, he considered these conglomerates as the detrital base of the Cretaceous transgression.

Langenheim, R.L., (1959) designated in the Lebrija river gorge a type section for the Giron Formation, a lithostratigraphic unit underlying the Tambor Formation of Morales et al., 1958. It establishes a correlation with the lithologies present in other localities, determining an important facies variation, and calling them western facies and eastern facies separated by the Giron fault (now known as the Suarez fault). He recognizes the lower and upper contacts of the Giron Formation as discordant. It also emphasizes the presence of conglomeratic layers in certain areas, while in other ones these conglomeratic facies do not appear and there it is quite difficult to recognize the contact of the Giron Formation with the overlying siliciclastic unit. Some of his key contributions are observable in Table 3.

Navas (1963) performed in some detail the stratigraphic study of the Giron Formation in the type section designated by Langenheim (1959) - See Table 1 and Table 3. On top of this unit he describes a thick package (120-150 m thick) of conglomerates that would constitute the top of the Giron Formation or the base of the overlying lithostratigraphic unit, known at this time as the Tambor Formation. The succession consists of pebbles and cobbles ranging from 5-30 cm diameter, rounded to semi-rounded, encompassed in a clayey matrix, the whole set has a reddish color, the gravel clasts consist of fine-grained quartz sandstone and compact shale. Its contact with the underlying and overlying lithostratigraphic units cannot be clearly determined at this place due to exposure problems. He also establishes that its continuity towards the south is confused, although these lithologies appear a few meters in the Piedra Azul brook. The main geological problem of this dense package of rudites arises from its position in relation to the top of the Jurassic or the base of the Cretaceous formations, but Navas decided to locate these conglomerates as the highest part of the Giron Formation.

Table 3: Additional ideas of the Jurassic-Cretaceous succession in Santander and Boyaca proposed by Langenheim (1959).

In the Jordan area south of the Los Santos town, the base of the lithostratigraphic unit overlying the Jurassic rocks was described as “a prominent white arkosic conglomerate about two or three meters thick occurs at the base”. Additionally, he adds: “the conglomerate is succeeded by buff sandstone alternating with red sandy shale and siltstone. Sandstone is, however, most abundant and forms an impressive cliff above a bench eroded in ten or twenty meters of interbedded sandstone, siltstone and shale. The massive, cliff forming sandstone comprises the top of the Tambor formation (*sensu* Morales *et al*., 1958), and is succeeded by Cretaceous black shale and limestone containing marine fossils”.
He mentioned that in the Ruitoque Mesa, there is no conglomerate at the base of the so-called Tambor Formation and the contact is arbitrarily located at the base of the first well-washed buff-colored sandstone. The layers of dark red shale are interbedded with white sandstone in the basal 15 meters of the Tambor Formation and are succeeded by white sandstone with an outstanding geomorphological expression forming a cliff and arranged in thick layers capping the Mesa.
He established that the Tambor Formation of this area is divisible into a basal conglomerate member, a middle member of interbedded gray sandstone and red shale or siltstone, and an upper cliff-forming sandstone member. These 3 members range widely in thickness and character within the area studied. The cliff-forming sandstone thins gradually northward but still forms an impressive cliff girdling the Mesa de Los Santos. On the Mesa de Ruitoque it is markedly finer and thinner.
He concluded that the Tambor Formation presumably represents continental and beach deposition at the beginning of the Cretaceous cycle of marine deposition. The red-beds of the lower and middle members probably derive their color from reworked Jurassic rocks.

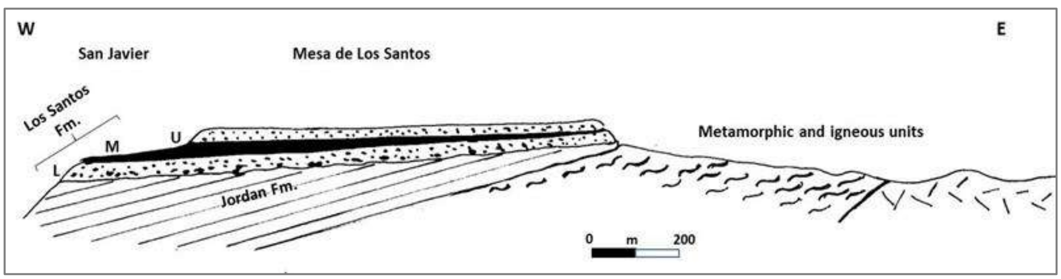

Figure 2. Relationship between igneous-metamorphic rock units, Jordan Formation and Los Santos Formation in the Mesa de Los Santos area. Modified from Julivert, 1963.

In the Mesas area (Julivert, 1963), explains that the lower and middle segment of the Tambor Formation (now knowing as the Los Santos Formation-see discussion below) get thinner towards the east, that is, towards the Santander Massif, even observing a discordancy on the eastern edge of the Mesas region between the lower and the upper segment, the middle segment being very reduced. This fact is observed on the road that goes up to the Mesas region where this formation is about 120 meters thick compared to more than 200 meters on the other edge of the Mesas - San Javier region (Figure 2). This is interpreted by Julivert (op. cit.) as the continuity of the tectonic positive movement of the Massif area with respect to neighboring areas during the basal Cretaceous deposition.

Julivert and Tellez, 1963 observed the Aratoca fault showing a sunken movement of its western limb. This fault does not present any evidence of fracturing or faulting of the basal sandy Cretaceous succession, a sequence known at this time as the Tambor Formation. In this case, the basal Cretaceous succession does not present any displacement at all, and unconformably covers both rock bodies, the Jurassic sediments lying to the west in faulted contact with Paleozoic igneous and metamorphic rocks eastward. Additionally, in Alto de Los Monos, the Jurassic faulted succession is perfectly fossilized by the structurally un-deformed basal sandy sediments of the so -named Cretaceous Tambor Formation, this being the site that allows the clearest determination of the pre-Cretaceous age of the fault. The fault is therefore of post-Jurassic and pre-Cretaceous age. As a general rule, pre-Cretaceous faults plunge their lips to the west.

To the south in the Mesa de Barichara region, more precisely in the Curiti creek, Tellez (1964) finds the apparent absence or considerable thickness reduction of the shale-dominated succession that is characteristic feature of the middle segment of the Tambor Formation (now this unit is known as the Los Santos Formation). This author assumed its reduction because there he only found seven meters of red shale interbedded with fine-grained muddy sandstones. His interpretation refers, in one way or another, that this fact would reveal a discordance between the lower and upper segments of the Tambor Formation. This discordance is also manifested in the NE part of the Mesa de Los Santos (Julivert (1963).

Julivert et al. (1964) argued that the base of the Cretaceous is formed by a siliciclastic unit (Tambor Formation at that moment) distinguished by three segments, a lower one of sandstone and some reddish conglomerates, similar in appearance to the underlying Jurassic unit; a middle part of reddish shale and thin beds of intercalated sandstones, and an upper part of white sandstones, very characteristic that form the entire surface of the Mesas region. In addition, they concluded that the fundamental tectonic feature in this region is the existence of large faults limiting tilted blocks.

Cediel (1968) described in detail the Giron Group establishing the type locality in the outcrops located in the narrowness of the Lebrija River. Following his description this group is composed of a series of sandstones and periodic intercalations of red shales ("red beds") with an estimated thickness of more than 4500 meters. The Giron Group was subdivided into the Jurassic Giron Formation, and the upper unit named as Los Santos Formation of probable Berriasian age - Figure 3 (a), Figure 3 (b). The lower lithostratigraphic unit of the Giron Group was described and interpreted by Cediel (1968) as composed of sub-greywackes and red shales that were deposited mainly in a fluvial or limnic-fluvial environment. The upper unit of the group, or Los Santos Formation, was interpreted as a marine deposit of proto-quartzites with occasional intercalations of red shale beds varying to dark shales at the top.

According to Cediel *(op.cit*.) the Giron Group unconformably overlies marine sediments of apparent Devonian, Carboniferous, and Permian age (Bocas Formation and a new-defined Jordan Formation), except locally where it rests directly on igneous or metamorphic rocks of the Silgara Formation. Towards the top of the Giron Formation (sensu Cediel, 1968) in a very small area, near the narrowness of the Lebrija River, it is outcropping a succession predominantly composed of "red beds" consisting in lithoclasts of conglomerates interbedded with sandstones and shales of a characteristic grayish-red color (5R4/2 to 10R4/2) and dark reddish brown (10R3/4). See conglomeratic representation at the top of the segment G in Figure 3 (a). This lithological succession was named the Tambor Formation by Hedberg (1931). In a study for the oil industry, Morales et al (1958) extend the name of the Tambor Formation further south from the type locality to the town of Zapatoca and surrounding areas, considering that they consist of conglomerates composed of reddish gray clasts of sandstones and siltstones, as well as fine-grained quartzose sandstones intercalated with red shales, assigning a thickness of 650 meters and an age between the Valanginian and late Hauterivian. Cediel describes these lithological association as the "conglomerados rojos" or red conglomerates, and it associates this one with fluvial blocks, coming exclusively from the red beds of the Jordan Formation, which according to his interpretation testify to strong uplifts in the source region shortly before the transgression of the overlying unit that he calls the Los Santos Formation.

Cediel (1968) was the first geologist to review the Tambor Formation denomination, showing strong evidence of the Morales *et al*. (1958) mistake. As a conclusion to this topic, the Tambor unit is not equivalent to the sequence widely known in the Mesas and Cuestas region and now known as the Los Santos Formation, a new formal definition by this author in the type locality of El Roto trail. In Figure 3 (b), the columnar sections of the new lithostratigraphic units defined by Cediel (*op. cit*.): the Jordan Formation and discordantly upon this one the Los Santos Formation.

Ward *et al.* (1973), although mentioning the proposal of Cediel, continued to use the term Tambor Formation to designate the sandstone-dominated interval below the Rosa Blanca Formation measured during the development of the geological mapping of the area. Pons (1982) based on palynological information, concludes that the Giron Group is Upper Jurassic-Lower Cretaceous in age.

The publication of the Cretaceous Project (Etayo-Serna & Laverde Montaño, 1985) was the basic reference work for the description and environmental re-interpretation of some of the clastic and carbonate units of the Lower Cretaceous of the Middle Magdalena Valley Basin. Laverde *in* (Etayo-Serna & Laverde 1985) re-described the Los Santos Formation in the El Roto trail type section and divided it into four segments, which updated to the present job are shown in Figure 3 (c) and listed in Table 4.

Clavijo-Torres (1985) in the section of the Piedra Azul brook and Laverde & Clavijo (1985) in the section of Tu y Yo, subdivides this unit into three segments: A (lower): conglomeratic sandstones and sandstones, B (medium): sandy mudstone and red-grayish mudstone, and C (upper): quartz-sandstone. In the segments A and C minor mudstone interbeds are present. They interpreted Los Santos as a fluvial deposit. Clavijo-Torres (1985), when describing the Los Santos Formation through the Piedra Azul creek located close to the Giron Group type area, refers to the presence of red conglomerates equivalent to those mentioned by Hedberg (1931) as the Tambor Formation and "conglomerados rojos" by Cediel (1968). For this reason, he correlates segment I of his study with the presence of the Tambor lithofacies in the Piedra Azul creek. Their facial analysis and interpretation conclude that these lithologies represent mudflows in a framework of alluvial fans. The overlying segments II, III and IV are correlated with the Los Santos Formation of Cediel (1968).

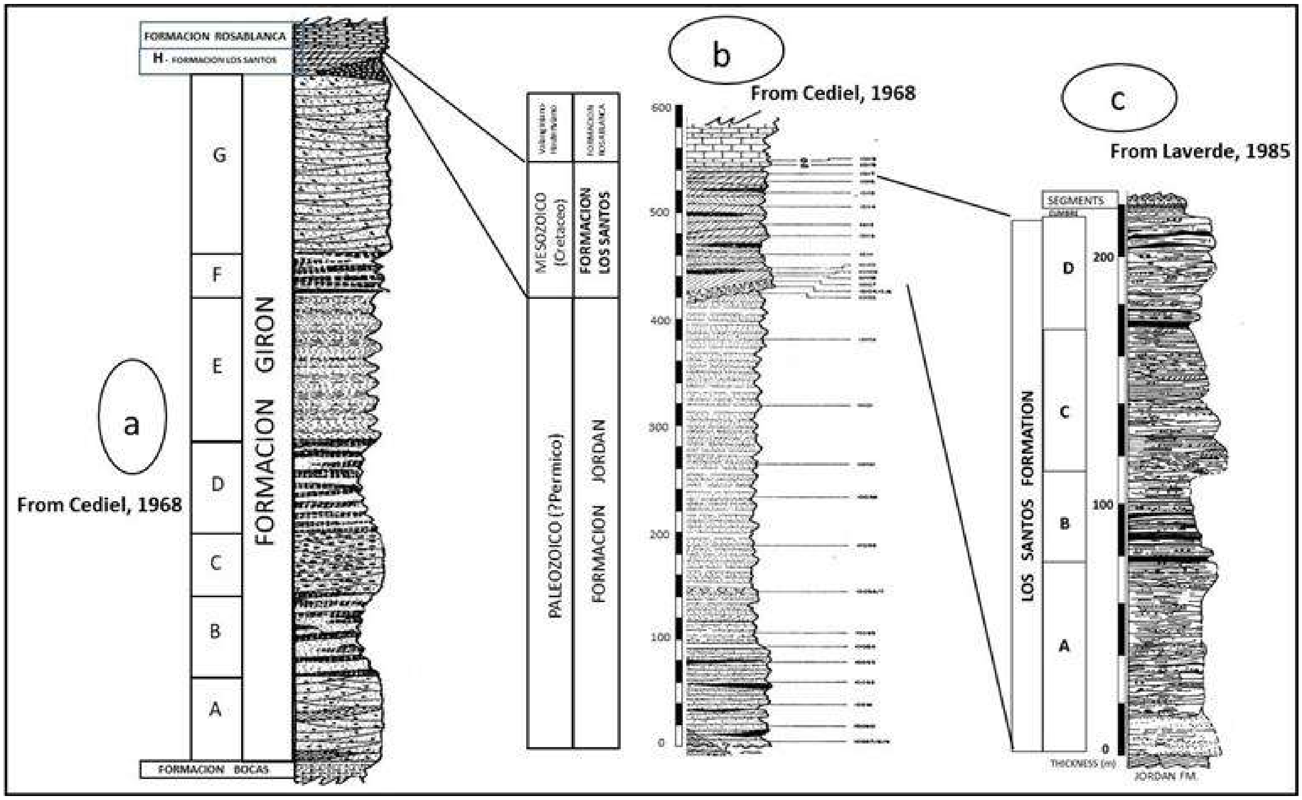

Figure 3. Stratigraphic columnar sections about the Giron and Los Santos formations. (a) Giron Group consisting of the Giron Formation in the type section of Lebrija river gorge and Los Santos Formation (after Cediel, 1968). (b) Stratigraphic column of the Jordan and Los Santos formations at the type locality for both units in the El Roto trail (Cediel, 1968). (c) Stratigraphic column of the Los Santos Formation in the type section of El Roto trail (from Laverde, 1985).

Table 4: Main subdivisions of the Los Santos Formation according to Laverde-Montaño (1985).

Segment A: Fining upward succession consisting of clast-supported to matrix-supported sandy conglomerates interposed by conglomeratic sandstones, medium-coarse-grained sublithic sandstones and local thin-bedded mudstones. Quartz and quartzite are the major components with some presence of lithic fragments from sedimentary and plutonic origin. Cut and fill structures, reactivation surfaces, and poor and localized bioturbation features in stratigraphic surfaces on the fine-grained sandstones.
Segment B: Thick-bedded mudstones to fine-grained muddy sandstones, locally pebbly sandstone lenses. Root structures are common, as well as, remnants of disseminated granular caliche.
Segment C: Thick to very thick-bedded package of planar cross-bedded sandstones, developing remarkable reactivation surfaces. Medium to fine grained quartz-rich sandstones, with some intercalations of thin-bedded to thick-laminae of muddy sandstones and clayey siltstones; Intraclasts of mudstones are distinguished, localized and scarce presence of granules and small pebbles in the form of elongated pulls. Plant remnants are scattered and poor bio-disturbance has been observed on some bedding surfaces. Syn-sedimentary deformational structures are present at the bottom set of this segment.
Segment D: In the lower part, an intercalated package of thick-bedded mudstone and thin-bedded, to very fine-grained muddy sandstones, abundant plant debris and root remnants of predominantly grayish-red with patches of grayish-green. Overlying, medium to thick bedded sandstones, some of them tangentially based cross-bedded, with localized reactivation surfaces, in other places flat parallel internal-stratified. The sandstones are quartzose, fine to very fine grained, and intercalated with thin to thick-bedded siltstones. The presence of earthy caliche in the form of patches or abundant pipe-shaped ichnofossils in the mentioned lithologies are remarkable. In the upper part of the segment, the increase in trace fossils, such as burrows and tracks is notable.

The Cretaceous Project showed two tendencies, a majority one, following the proposal of Cediel (1968), and another retaining that of Morales et al. (1958). These proposals caused confusion in the scientific community resulting in the indiscriminate use of both terms. To clarify this situation, Etayo-Serna (1989) confirmed most of the Cediel´s work and proposes a partially new nomenclature, in which the following units are included from oldest to youngest: "A) The Girón Group, comprised of, B) The Angostura del rio Lebrija Formation, which outcrops in the narrowness of the Lebrija River, a new formation that constitutes the lower unit of the Group, C) The Los Santos Formation, or upper unit of the Giron Group, with a type section in the "El Roto" trail (Cediel, 1968). In the uppermost part of the Angostura del rio Lebrija Formation, it situates the local unit of the red conglomerates and establishes that these be called the Tambor Member, thus establishing the change of lithostratigraphic category formally for the unit originally described by Hedberg (1931) as the "Tambor Formation", mistakenly extended by Morales *et al.* (1958) and mentioned by Cediel (1968) as the "Red Conglomerate" of its Girón Formation. Likewise, it adopts as the type locality of the Tambor Member the one originally described by Hedberg (1931) between km 92 and 95 of the Bucaramanga-Barrancabermeja old railway. He considers that the Tambor Member is a lithosome inserted in the uppermost part of the Angostura del rio Lebrija Formation.

Clavijo and Camacho (1993) described the Tambor Member as a clast-supported conglomerate of subrounded and rounded pebbles and blocks (10-50 cm), in a muddy matrix (20-30%). The clasts are mostly fine-grained sandstones and red-gray siltstones; Minority fragments of effusive and pyroclastic volcanic rocks are found. In addition, they mention that the conglomerate has an approximate extension of 4-5 km. Because geologists working in the area found the name Angostura del Río Lebrija Formation quite impractical and due to additional criteria that are referred to in the Code of Stratigraphic Nomenclature, Clavijo and Camacho (1993) found that the most appropriate was to use the name of the Rio Lebrija Formation instead of the one proposed by Etayo-Serna (1989). This new denomination is the one used in this paper.

Moreno-Sánchez (2019) under the supervision of Dr. Etayo-Serna in the stratigraphic framework that accompanies the geological map prepared for the Geological Survey of Colombia, in the Sogamoso river canyon, Villanueva, Zapatoca and Betulia sector,).

department of Santander affirms to follow the works by Navas (1963) and Cediel (1968) for the Jurassic units. As a result of this, the now called Giron Group is subdivided into four lithostratigraphic intervals named from base to top as established by Navas (*op. cit*.): "Intervalo arenitico inferior", "Intervalo lodolitico inferior", "Intervalo arenitico superior", and "Intervalo lodolitico-arenitico". In this way, the Los Santos Formation is excluded as an integral part of the Giron Group.

The objective of Torres and Lizarazo, in 2020, was to establish a clearer understanding of the meaning of the so-called Tambor Member last named by Etayo-Serna in 1989. They measured stratigraphic columns in two localities with varied exposure within the type area of this unit. They named these sections as Peña Morada and El Cerro. The first is located in the narrowness of the Lebrija River (Km 95 of the old railway line that connects Puerto Wilches with Bucaramanga), and the second in the road that connects the village of La Popa with the El Tambor farm, in the Municipality of Rionegro, Santander. Due to the tectonics that occurs throughout the work area, the Peña Morada section consisted of the measuring of a composite column based on two separate sections. In this column they present the description of some meters of the gravelly succession named by Etayo (1989) as the Tambor Member and a few meters from the overlying succession denominated as Segment II by Clavijo (1985), and studied by Clavijo and Camacho (1993) as the base of the Los Santos Formation. In the stratigraphic section of El Cerro, they determine the presence of this succession dominated by red conglomerates and its contact with the underlying succession of the Rio Lebrija Formation. The determined thickness of 465 meters for this ruditic succession is quite anomalous, since they present many covered intervals and the subsequent tectonism have affected the mentioned thickness of the gravelly unit under study.

2.1. Brief tectonic scheme of the work area

The understanding of the main tectonic features of the work area allowed a better definition of the stratigraphic framework of the Los Santos Formation. A briefly summarizing scheme (Table 5) shows the main contributions to this topic from qualified researchers who, from the first foundation made by Julivert (1958), have been growing in the achievement of new data, in the modern and integrated interpretation of the rocks that make up the late Jurassic to Early Cretaceous in the Mesas and Cuestas area. See Figure 1 (a), Figure 1 (b

Table 5: Summarized scheme of new data and interpretation of some researchers about the tectonics of the work area.

1. Fabre (1983); Cooper *et al.* (1995); Sarmiento-Rojas *et al*. (2006); Velandia (2017); Osorio and Velandia (2021), among others suggest that extensional tectonism created several half-graben systems that were filled with thick volcanoclastic and clastic sequences of mostly continental affinity. An example in the present study area is the Jurassic Yariguíes anticlinorium, sometimes called Yariguíes basin by Velandia (2017) and Arcabuco-Norean Basin in relationship with isolated igneous-metamorphic massifs such as the Floresta and Santander High respectively (Jimenez *et al*., 2021).
2. Sarmiento-Rojas *et al*., (2006) suggest that lithosphere stretching has been the "engine" to produce ENE-WSW–striking normal faults and generating a relatively fast subsidence that controls the latest Jurassic–Early Cretaceous basin configuration during the deposition of continental sequences. The Suarez, Bucaramanga, Boyacá, Río Servita among other faults are some of these structures, being part of a rift shoulder in contact with basement highs, sub-basins, or depressed and sunken areas (Osorio and Velandia, 2021).
3. Bayona *et al*. (2006) based on paleomagnetic declination data, suggest counterclockwise rotations of approximately 90° in the displacement of fault-bounded blocks, concluding that these rotations took place before syn-extensional deposition of Jurassic to Lower Cretaceous sequences.
4. The synrift successions were segmented by transverse structures and regional longitudinal faults of the rift-shoulder, as the Suarez Fault. The tectonic frame of the study area shows the relevance of the W-E compressional regimes, explaining the local kinematics as a heritage of the former configuration and tectonic inversion of the basins (Osorio and Velandia, 2021).
5. As part of a high tilt to the west, the Bucaramanga and Lebrija paleo faults formed an elongated basin (Arcabuco-Norean) on the edge of the massif that was continuous to the south with the Boyacá and Pueblo Viejo faults (Velandia, 2017). Although Velandia (op.cit.) considered the Lebrija Fault as a single structure and the west border limit of the Santander High, some geologists have treated this fault separately of the Los Santos fault, because structural complications are present in the regions surrounding the Mesa de Los Santos, and consequently there is no clear evidence of the connection between these two faults.
6. An oblique structure to the Arcabuco-Norean basin that was configured between the current Bucaramanga and Lebrija faults, is the most extensive and thicker sediment pile of the Giron Group, which appears to be associated with the Suarez Fault (Velandia 2017). This big structure is referred to as a basin due to its oblique geometric relationship with the main faults of the Santander High. Consequently, this structure can be interpreted as a traction basin in a transversal or transfer zone with respect to the Arcabuco-Norean basin on the edge of the Santander High (Osorio and Velandia, 2021). The subsequent tectonic inversion of this basin occurred in several phases (Osorio, 2016).
7. The Bucaramanga Fault defines a positive and relatively symmetrical flower structure with the east block bounded by the Guamalito Fault and the west block bounded by the Lebrija Fault. The western limit of the Santander Massif would then be configured by the Lebrija Fault and its eastern limit by the main structure S2M2 (Velandia, 2017).
8. Ward *et al.* (1977b) performing the geological map of this area, mapped the Lebrija fault, based on the differentiation of Cretaceous and Paleogene sedimentary rock units in faulted contact with Paleozoic and Jurassic rocks to the east. At the present time the Lebrija fault is mapped as a reverse fault, that has a good regional continuity parallel to the Bucaramanga Fault, configuring a new zone relatively elongated. Velandia (2017) describes some oblique folds and synthetic (R) and antithetic (R') lines, which are indicative of sinistral movement.
9. The Yariguíes Basin was one of the multiple depressions generated during the lithospheric stretching and extension, limited by former normal faults (Velandia, 2017). For this reason, the Yariguíes Basin is also proposed as the main deposit area for Jurassic sedimentary rocks (Girón Group). Also known as Los Cobardes Anticline, the inverted basin shows the greatest thickness in the area. Due to its oblique relationship with the Arcabuco-Norean basin, it is considered a traction basin in a transfer zone during Jurassic stress tectonics (Velandia, 2017).

10. The Suarez fault is a pre-existing early Mesozoic normal fault, tectonically inverted structure that controlled the exhumation of the Los Yariguíes anticlinorium (Teson *et al.*, 2013; Jiménez *et a*l., 2016, Jimenez *et al*, 2021, Osorio and Velandia, 2021) with reverse sinisterly displacement during crustal shortening (Sarmiento-Rojas et al., 2006; Tesón *et al.,* 2013).

11. The ENE-WSW oriented traverse structures are developed by affecting the NW-SE regional trend of the main faults. The Los Montes fault (referred to as the El Monje fault by Jiménez *et al*, 2021) is a structure interpreted with a normal sense of movement and responsible for some kind of basin segmentation during the deposition of the Girón Group (Araque and Otero, 2016). Another example is the Jordan Fault, interpreted in this study as an active structure at least during the late Jurassic, until it was buried by the middle and upper part of the Los Santos Formation, which does not allow it to be visualized on geological maps at the present.

12. An oblique to transverse structure is the NW-SE oriented Sogamoso fault (referred as the El Tablazo fault by Osorio and Velandia, 2021) interpreted in this study as a normal fault with a hanging wall toward the Zapatoca syncline, that has been argued by different geologists as responsible for the present orientation of the Sogamoso river. This fault cut some structures in the opposite ways of the fault trace. This fault behavior could be shown in the stratigraphic sections of Part B of this revisiting exercise.

13. Velandia (2017) has interpreted faults that are not regionally extensive, but restricted between the main longitudinal faults and whose right-hand kinematics are partially documented. Between the Bucaramanga and Lebrija faults, a dextral sense of movement could also be interpreted as for example in the Solferino and Los Montes faults. These structures present mainly normal kinematics within the west block of the Bucaramanga flower structure, although they may also present dextral oriented movement as noted by Araque & Otero (2016).

3. The Lowermost Succession of the los santos formation

The base of the Los Santos Formation and the type of contact with underlying units has been the subject of controversy that has not yet been satisfactorily resolved. Based on a new analysis, this article documents some geological features that enhance their importance in the events that occurred before the start of the Cretaceous marine invasion. The survey and/or revision of twelve (12) stratigraphic columns that cover most of the lower portion of the Los Santos Formation, identified as Segment A in this study and the work of Laverde (1985), and mentioned again in the part B of this revisit exercise of the Los Santos Formation, allows a first look at instance the schematic representation of twelve stratigraphic columns that cover most of the lower portion of the Los Santos Formation-Segment A (Figure 4).

In a general sense, some geologic features are remarkable when trying to understand the bottomset of the Los Santos Formation. The rock types and the mineralogical composition of these ones show some differentiation in different areas:

1. East of the Suarez fault and south of the Los Montes fault the basal Los Santos Formation is constituted by conglomeratic rocks whose main compositions are quartz, chert, quartzite and smaller percentages of igneous and metamorphic rocks. These conglomeratic rocks are intercalated with sandstones and in smaller proportions mudstones. The Los Santos Formation rests over an igneous and metamorphic unit's domain or over the Jordan Formation.

2. Complex structures and sedimentary response to them are located north of the study area near the Lebrija and Solferino faults (see stratigraphic column 12). These deposits consist of conglomeratic successions constituted by dominant brownish red sedimentary lithoclasts of intercalated conglomerates, sandstones and minor mudstones, apparently from the Jordan Formation detritus. This pile of sediments is observable toward the south showing variations in the number of red beds (i.e., stratigraphic columns 2 and 3), where there is a presence of these brownish red clastics but in minor proportions.

4.

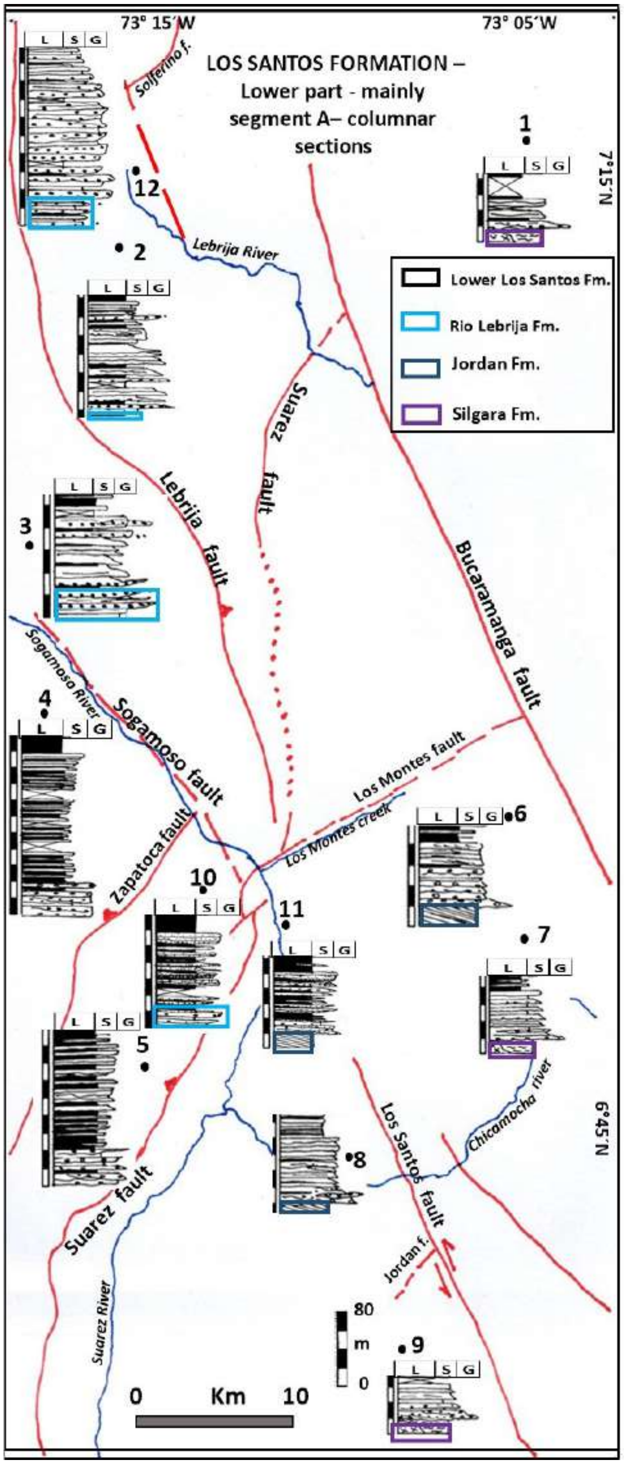

Figure 4. Schematic representation of twelve stratigraphic columns that cover the lowermost portion of the Los Santos Formation- or Segment A: 1. Charta (modified from Santana, 1986); 2. Piedra Azul (Clavijo, 1985); 3. Pujamanes (Renzoni, 1985); 4. Tu y Yo (modified from Laverde and Clavijo, 1985); 5. Platanalito (Laverde et al , in progress); 6. La Punta (modified from Rincon,2008); 7. Carrizal (modified from UIS-IGM, 2006); 8. El Roto (Laverde, 1985); 9. Curiti (modified from Santana, 1986); 10. Ojo de Agua (Laverde et al. ,in progress); 11. El Calicho (modified from Aldana, 2008); 12. El Cerro (modified from Torres and Lizarazo, 2020). The trace faults are representing the main structural features affecting the Los Santos Formation.

3. The block located westward of the Suarez fault and south of the Sogamoso fault shows the presence of the Río Lebrija Formation, on which were deposited predominant sublithic sandstones and mudstones that form the base of the Los Santos Formation. In this domain, the Los Santos Formation does not present any significant conglomeratic facies.

3.1. East of the Suarez Fault (footwall block) and south of the Los Montes fault

Laverde (1985) at the type section of the Los Santos Formation located in the trail to "El Roto" made a detailed description of the constituent facies of conglomerates and sandstones found at the base of the unit. In the aforementioned work, he presented the most characteristic facies of the Los Santos Formation, which are also briefly alluded to here; but this article shows not only those presented in that time, but also others that have complemented the understanding of this issue. This integrated analysis has served to understand its distribution and regional significance. The specific facies defined by Laverde (1985) are briefly described in Table 6

.**Table 6. Los Santos lowermost facies definitions at the El Roto type section (Laverde, 1985).**

Gfm: Matrix-supported fine-sized sandy conglomerates	Gmm: Matrix-supported medium-size conglomerates
Gmc: Clast-supported conglomerate, pebbles and cobbles, disordered and polymodal.	Gfc: Clast-supported fine-sized sandy conglomerates
Gcc: Clast-supported conglomerates, polymodal, cobbles>blocks, matrix coarse-grained sand and granules.	
SCp: Conglomeratic Sandstone, medium-grained, plane-laminated	SC: Medium grained conglomeratic sandstone
Sp: Plane-laminated, fine-grained sandstones	Sm: Massive medium to coarse-grained sandstones
SCm: Conglomeratic massive sandstone	Fm: Mudstones
Spi: Parallel-laminated or slightly inclined stratification of very-fine-grained sandstones to muddy sandstones	

The integration of these specific facies, as well as a better observance of the character of the conglomeratic rocks fabric, has given rise to the definition of four (4) lithofacies with important gravelly content and then an additional one more that documents the gradation or superposition to a sandy succession. The defined lithofacies are:

Lithofacies 1A: *Simple, disordered fabric, poor sorted, polymodal, matrix-supported sandy conglomerate (Figure 5).*

Figure 5: (a) Net and erosive contact of the Los Santos Formation over the Jordan Formation in the El Roto trail, Los Santos Formation type locality. The succession starts at the bottom with grayish red medium to coarse-grained sandstones, slightly conglomeratic (small pebbles), overlain by a "floating package" of sandy conglomerates mostly unordered fabric, mainly matrix-supported, pebbles and cobbles up to 9 cm diameter, rounded to subrounded, composed by clasts of quartz-quartzite, granitoids and in minor proportion of volcanic fragments. (From Laverde, 1985). (b) Matrix-supported muddy-sandy conglomerates consisting of pebbles, cobbles and blocks that are encased or "floating" conforming a disordered fabric, angular to sub-rounded gravel-size clasts, composed by quartz, quartzite and granitoids. Sub-vertical-elongated, faceted and outsized gravel clasts embedded in a muddy matrix, suggests mudflow gravity deposition (debris flow deposits). La Punta stratigraphic section.

Lithofacies 2: *Simple, crudely organized fabric, massive-bedded and roughly normal or reverse grading (Figure 6 and Figure 7).*

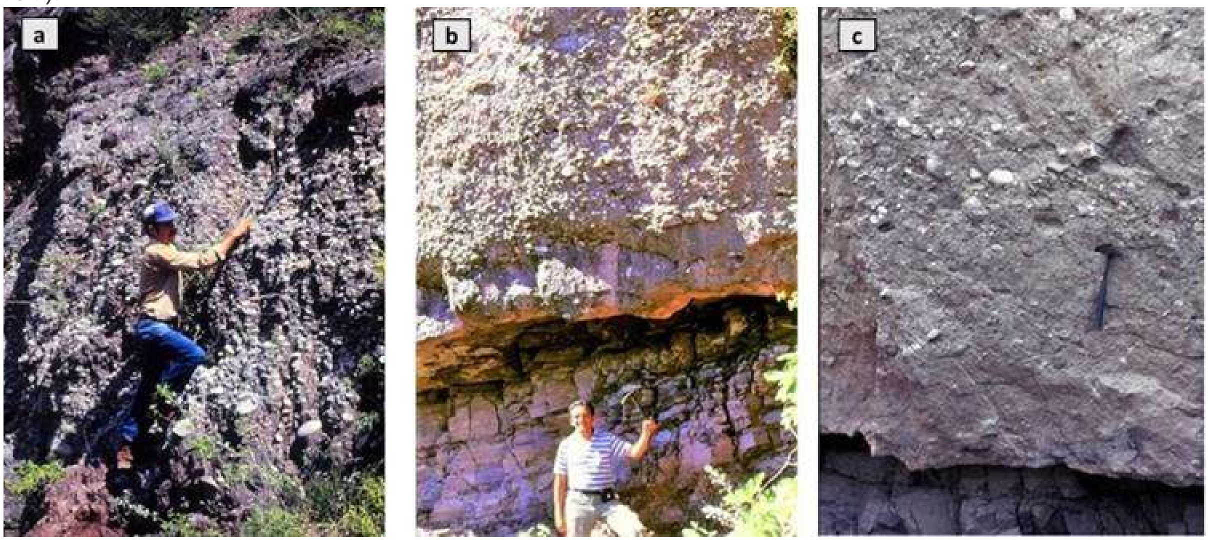

Figure 6. Examples from the El Roto trail section. (a) The contact between the Jordan Formation with the base of Los Santos Formation in the type section (see toe of the field assistant) sometimes presents a very thick package of dominant dark-reddish brown color, crudely fining upward trend, massive bedded, matrix -supported sandy conglomerate with pebbles and cobbles up to 9 cm diameter, well rounded to subrounded, some of them elongated following bed attitude. They are mainly composed of quartz, quartzite and sedimentary lithics. The sand-size fraction consists of medium to very coarse grained, subangular to subrounded, with important lithics coming from the Jordan Formation. The whole succession is graded to pebbly sandstones. (b) Medium to thick-bedded very fine-grained sandstone and siltstone of the Jordan Formation are overlain by an irregular and erosive contact of wedge-shaped, medium-bedded conglomeratic sandstone and a very thick-bedded package of clast-supported conglomerate, rounded to subrounded pebbles and cobbles up to 8 cm diameter, fair sorting, crudely normal graded, massive appearance. (c) Irregular, erosive and discordant contact between the siltstone beds of the Jordan Fm and the crudely coarsening upward succession of the Los Santos Fm consisting of conglomeratic sandstone grading to unordered, reverse, matrix-supported sandy conglomerate, with clasts up to 8 cm diameter, mostly rounded, good sphericity (From Laverde, 1985).

Figure 7. Examples from the Curiti creek: (a) Net, Irregular and erosive contact between the foliated micaceous phyllites of the Paleozoic Silgara Formation and the overlying matrix-supported, massive and very thick- bedded of conglomerates of the Los Santos Formation. (b) Thick, polymictic, orthoconglomerate beds define the base of the Los Santos Formation at the Curiti section. Clasts consist of milky-quartz and quartzite, minor phyllites and chert, mostly subangular to well-rounded and are typically 15-95 mm in diameter (rare clasts reach 400 mm diameter). They have moderate sphericity but can be angular where phyllites clasts dominate. The matrix is typically composed of quartzose to lithic sand. The orthoconglomerate shows crudely normally graded bedding. Generally, the conglomerate shows poor sorting to weak imbrication of clasts. Tightly packed clast-supported sandy conglomerate overlying in irregular and erosive contact the foliated micaceous phyllites of the Silgara Formation. The gravelly rock is poor sorted, being the coarse tail indicative of a normal grading.

Lithofacies 3: *Simple fair ordered fabric, crudely to fair developed flat lying stratification (Figure 8)*

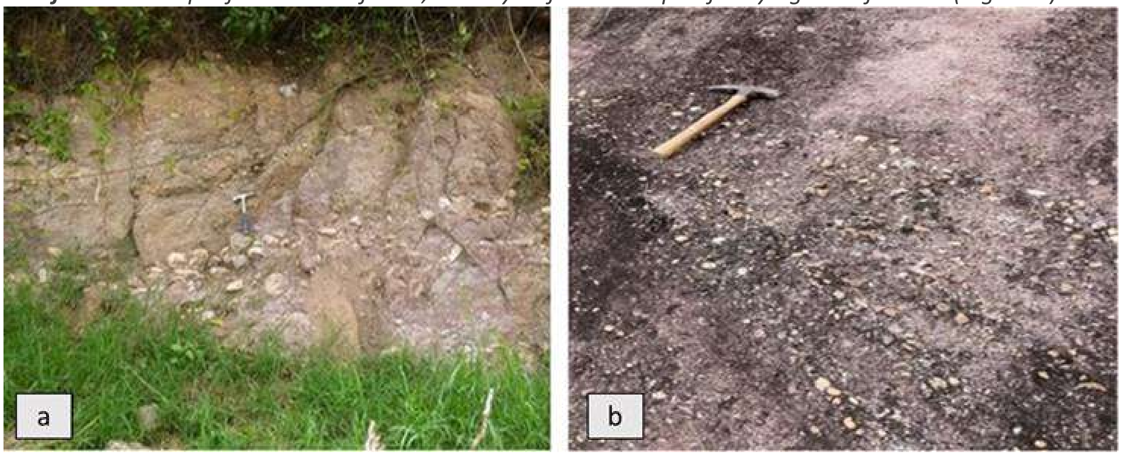

Figure 8. (a). La Punta section showing the lower half of the photograph a coarsening-upward succession consisting of muddy sandstones varying to medium to very coarse-grained, pebble conglomerate, nearly clast- supported with poor imbrication development. The upper half is a medium to coarse-grained sandstone with local granules and pebbles up to 12mm diameter. (b) El Roto section. Simple coarsening upward trend of the amalgamated very thick-bedded medium-coarse-grained sandy conglomerate underlying a thick-bedded, medium-grained scarcely small pebbly sandstone defining a simple ordered fabric with crudely flat lying stratification.

Complex and composed lithofacies 3 (Facies Association 3) - Figure 9: The entire facies association is composed by matrix and clast-supported conglomerates, conglomeratic sandstones, and sandstones intercalations (See Table 6 for facies identification).

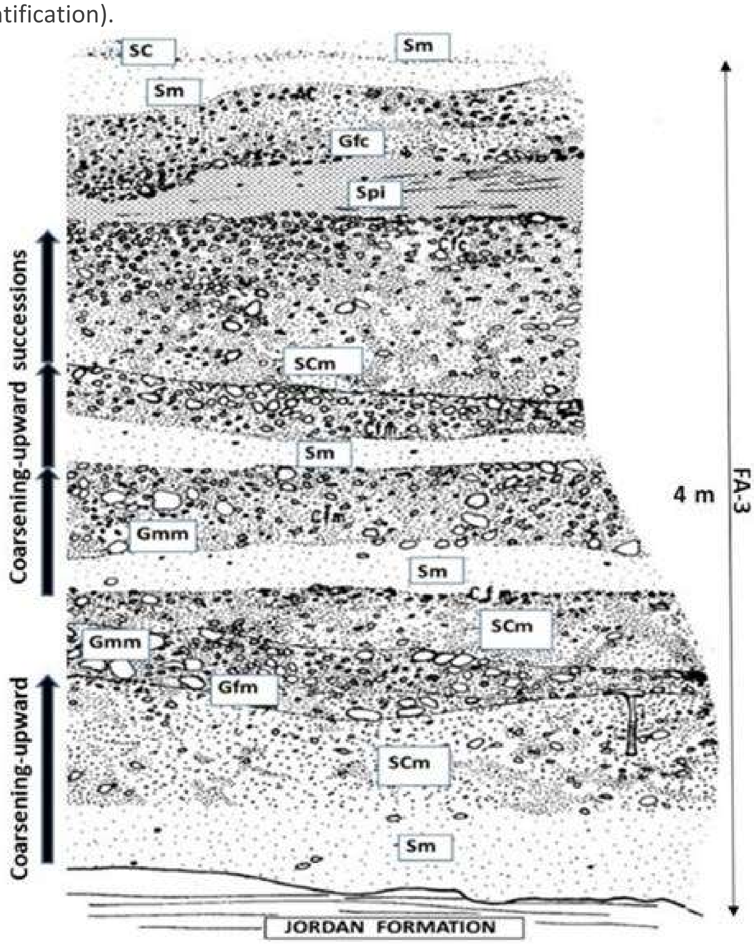

Figure 9: Outcrop representation at the El Roto type section of a very thick package of dominant conglomerates and intercalated sandstones bodies showing crudely flat lying stratification. The gravelly rocks are mainly reverse graded, while others are presenting disordered fabric (From Laverde, 1985).

Lithofacies association 3 passing into the ***lithofacies 4 (Horizontal stratification)*** - Figure 10:

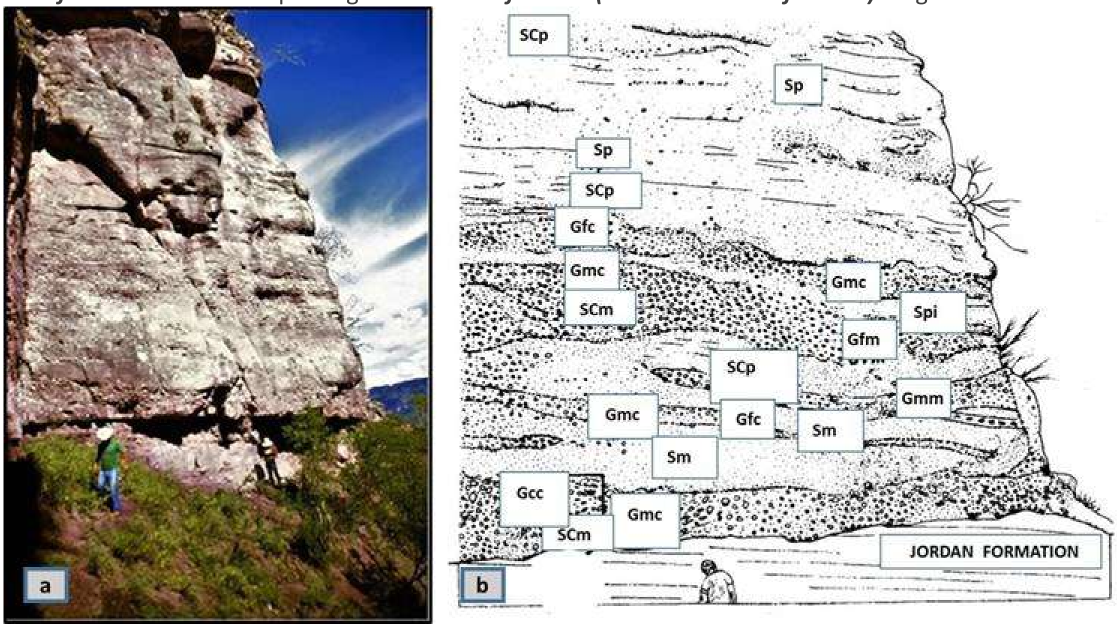

Figure 10: The contact between the Jordan and Los Santos formations is net, erosive and discordant. Internally there are lenticular bodies of medium to coarse rudites and thinner sandstone intercalations (lithofacies association 3), that vary to regularly-defined horizontal stratification of small pebbly stringers and dominant conglomeratic sandstones (lithofacies 4). (a) An outcrop photograph which is interpreted in the detailed scheme to the right as (b). From Laverde, 1985.

Lithofacies 4 (conglomeratic sandstones) passing into the ***lithofacies 5 (sandstones) - Horizontal stratification*** - Figure 11:

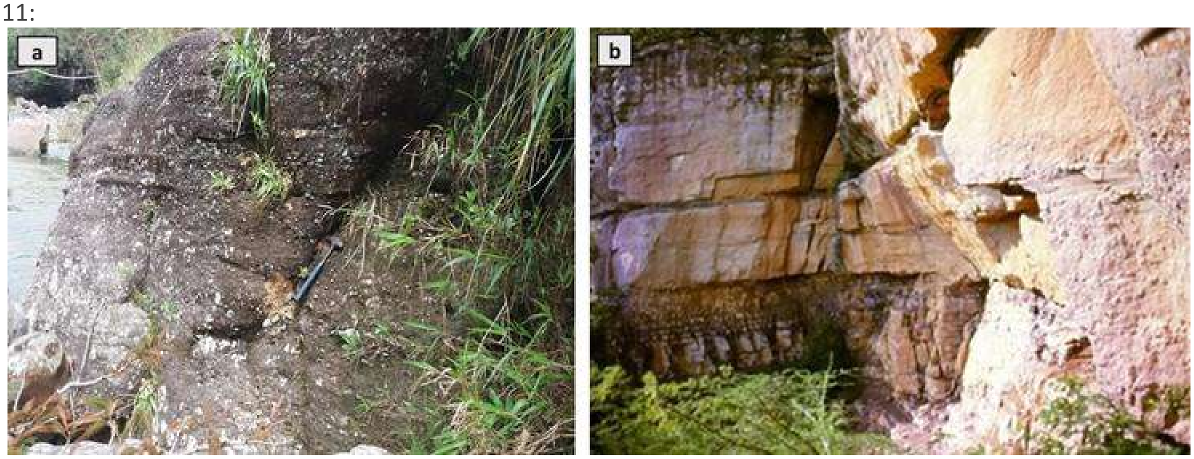

Figure 11: (a) Conglomeratic sandstone bed with horizontal stringers of granules and small pebbles in the Curiti creek. (b) Lithofacies 4 passing into lithofacies 5 in the El Roto outcrop. In the left and center of photography grayish red lithology, thin to thick-bedded horizontally-lying strata of siltstone and fine-grained sandstone of the Jordan Formation, is overlain by a sharp, low-angle discordant contact, tabular geometry of two very thick-bedded buff medium-grained sandstones which are separated by a thin-bedded sandy mudstone. To the right, a broken piece of a massive-bedded conglomeratic sandstone with the same thin-bedded muddy intercalation is manifesting a rapid facies change at the bottomset of the Los Santos Formation.

3.2. East of the Lebrija fault and west of the Solferino faulted areas

3.2.1. Rio Lebrija Formation . The Rio Lebrija Formation consists of alternating coarsening-upward and fining-upward successions. Very thick-bedded layers predominate over thick and medium-bedded layers. The massive bedding is a characteristic feature. Most of the facies consist of yellowish gray (5Y7/2) sublithic to pinkish gray sub-arkosic sandy conglomerates intercalated or varying to medium-very coarse-grained pebbly sandstones. They are subangular to subrounded, fair to poor sorted, mainly composed of quartz, chert, feldspar and varied types of igneous and metamorphic lithoclasts. These lithologies are intercalated with sandy mudstones of red color (5 R 4/6) - see Figure 12

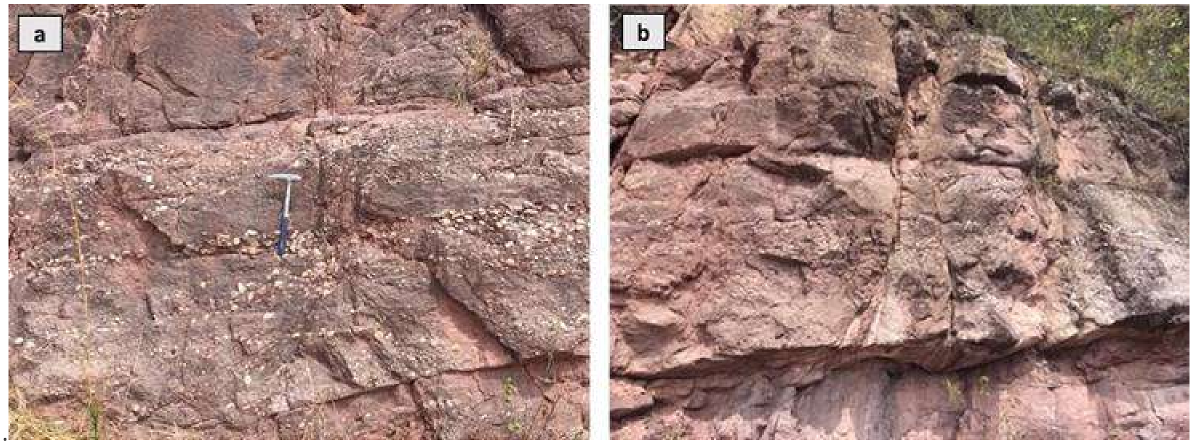

Figure 12: Rio Lebrija Formation at the Lebrija river gorge. (a) At the base, net contact of crudely coarsening-upward succession made up of conglomeratic sandstone to sandstone that in sectors corresponds to clast-supported sandy conglomerate. In the upper third of the photograph, a net flat surface demarcates a very thick layer of medium-grained sandstone. (b) A muddy sandstone bed is overlain by an irregular basal contact of a fining-upward succession consisting of pebbly sandstone medium-to coarse-grained grading into medium-fine-grained sandstone at the topset.

3.2.2. Los Santos Formation - Lowermost part

The reconnaissance of the basal part of the Los Santos Formation was achieved in the following outcrops of the Lebrija highland area:

- The Peña Morada and El Cerro stratigraphic sections correspond to the El Tambor High, following the work of Torres and Lizarazo (2020) and Tambor type section (Hedberg (1931), Cediel (1968) and Etayo (1989).
- The Lebrija River, old railway line, km 95 to km 92,5
- The Piedra Azul outcrop situated immediately southward of the narrowness of the Lebrija river, studied by Clavijo (1985).
- The Pujamanes succession based on the study performed by Renzoni (1985).

In the type section of the Los Santos Formation and surrounding areas located to the east of the Suarez Fault it was possible to determine the presence of four conglomeratic lithofacies at the base of the unit, but in this area located in the Lebrija and Solferino fault areas the following lithofacies could be determined at the bottomset of the Los Santos Formation

:

Lithofacies 1A: *Simple, disorganized fabric, matrix- supported, poor sorted, polymodal***-** Figure 13:

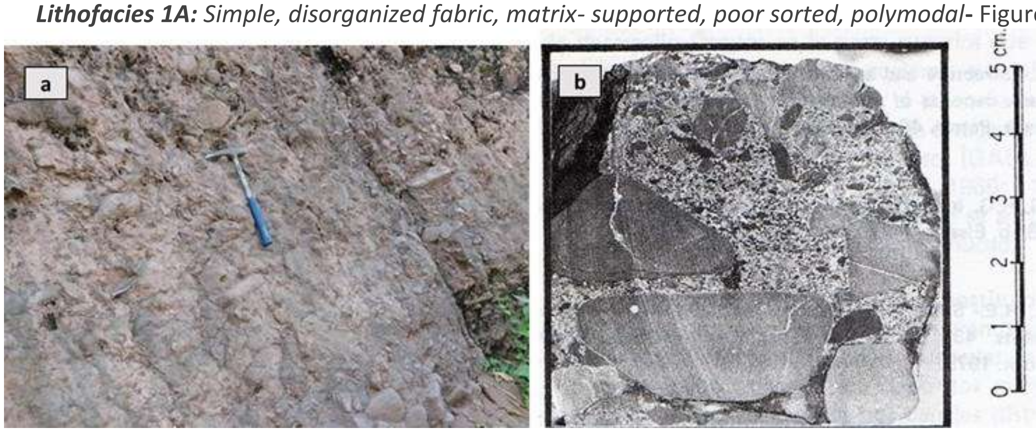

Figure 13: Lithofacies 1A general features. (a). Matrix-supported conglomerate, consisting of granule to pebbles and rare cobbles up to 20 cm diameter, coarse to very coarse-grained sand, and 5-10% percentage of mudstone. The whole fractions present disorganized fabric, very poor sorting, subangular to well-rounded clasts. Larger clasts are elongated and parallel to stratification, some of them are obloid in shape. All the detritus conforming the rock are lithoclasts of siltstone to fine to medium-grained sandstones reddish gray-colored. Rio Lebrija gorge, old railway line, approximately Km 93,3. (b) Disordered, ungraded, matrix-supported sandy-muddy conglomerate, consisting of pebbles and cobbles up to 7 cm diameter, floating in a muddy-sandy matrix of mainly coarse-grained sand. Very poor sorting, subangular grains in the sand fraction and sub-rounded to rounded in the gravel fraction. Composed by quartz = 50%, sedimentary lithics = 48%, Feldspar = 2%. Piedra Azul stratigraphic section (photography from Clavijo-Torres, 1985).

Lithofacies 1B: *Simple, disorganized fabric, clast- supported, poor sorted, polymodal-* Figure 14:

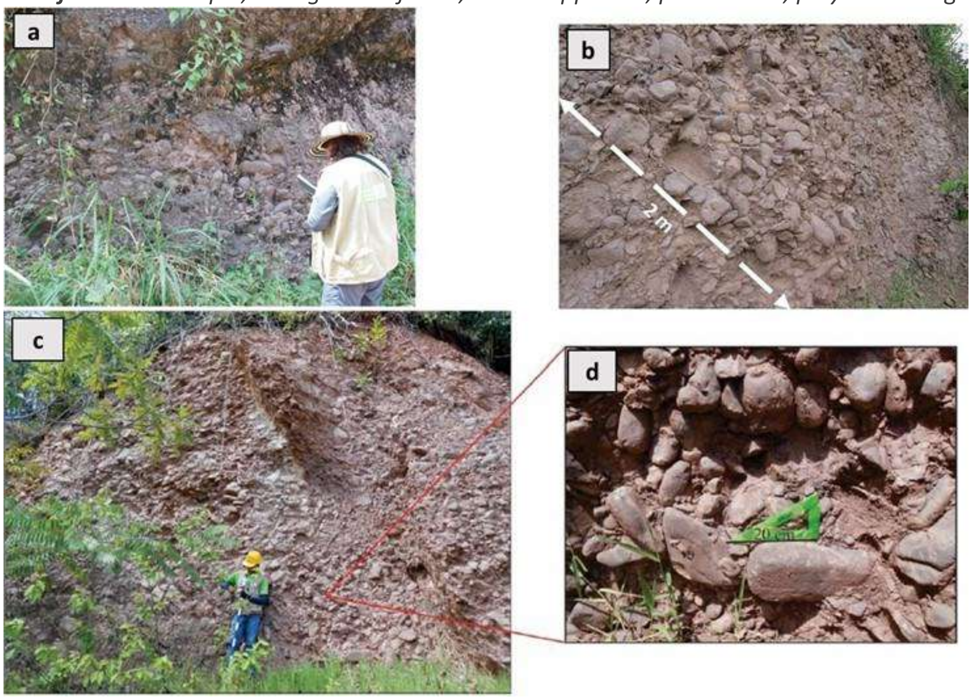

Figure 14: Lithofacies 1B. (a) Very thick-bedded, tightly packed or massive-bedded, unordered fabric, clast-supported sandy conglomerate, pebbly-sized, up to 7 cm diameter, rounded to sub-rounded clasts, fair to good sphericity, poor sorting. Composed by clasts of reddish gray sandstones and siltstones. Medium to coarse-grained sandstones (15-20% of the rock) infill de gravel size. Km 94 old railway line close to the Lebrija river. (b) Very thick, highly packed, massive bedded, unordered clast-supported sandy conglomerate, scarce muddy and sandy matrix, poor sorting, sub-rounded to rounded clasts, fair to good sphericity. Composed by reddish gray fine-grained sandstones, siltstones and mudstone clasts. Outcrop in Km 93,8 of the old railway line close to the Lebrija river. (c) and (d) Very thick package of disordered dominated clast-supported pebble to cobble sandy conglomerates, disordered fabric, sub-vertical to sub horizontal clast- arrangement, sub-rounded to rounded, some of them elongated, other fair to good sphericity, composed entirely by sedimentary lithic clasts (reddish gray siltstone and fine-grained sandstone). Photography from the middle part of El Cerro stratigraphic section from Torres and Lizarazo (2020) study.

Lithofacies 4A: *Horizontally stratified thick-bedded conglomerates and very thick packages of sandstones in alternation -* Figure 15:

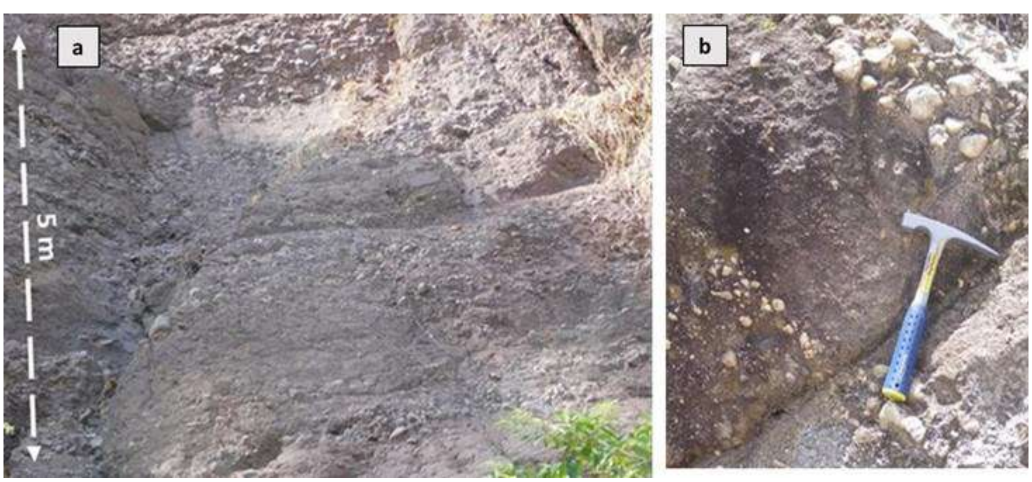

Figure .15: (a) Intercalated horizontally stratified thick-bedded conglomerates and very-thick packages of muddy sandstone to sandstones. The rudites are mainly clast- supported, granule to pebble sized, fairly-sorted, rounded to subrounded, composed by lithoclasts of fine-grained sandstones and siltstones. The sandstones are fine to medium-grained, locally with presence of mud matrix. Approximately Km 95, 2 old railway line close to the Lebrija river gorge. (b) Horizontally-stratified, thick to very thick bedded, coarsening upward sandstones and conglomerates at the Pujamanes section.

Lithofacies 4B: *Dominantly flat-lying strata of alternated very thick packages of conglomerates and thin to medium-bedded sandstones* - Figure 16 and Figure 17:

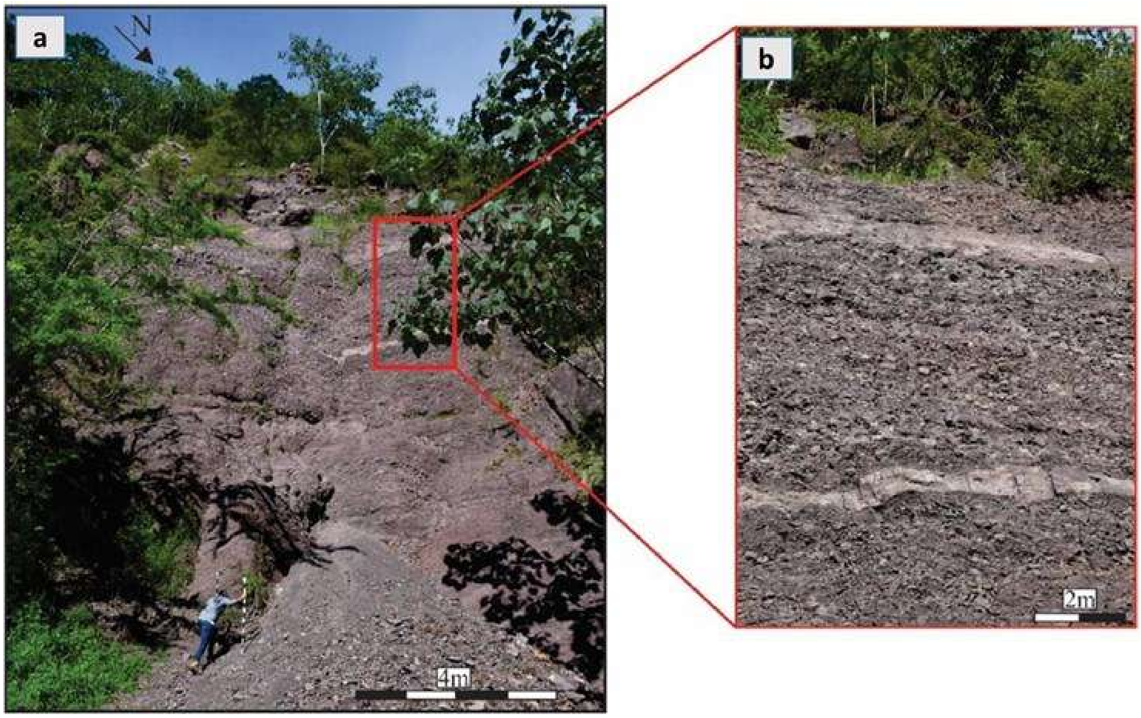

Figure .16. (a) General aspect of the lithofacies 4B. (b) A close-up of thinly layered sandstones which are interposed in a dominant pebble-sized conglomerates, well-to fair sorted, rounded clasts, massive-bedded appearance. The sandstones are fine-medium-grained, fair-sorted sublithic. Photographs from Peña Morada 1 section taken by Torres and Lizarazo (2020).

Figure 17. A very thick package of lithofacies 4B showing grayish red mudstone that varies to muddy fine-medium-grained sandstone containing disseminated granule to small pebble-size clasts of lithoarenites and minor percentage of quartz clasts. At the topset two medium-bedded and horizontally-stratified greenish gray sandbodies. Lebrija river gorge, Km 95 old railway line.

3.3. West of the Suarez Fault -south of the Sogamoso fault (Zapatoca block area):

3.3.1. Rio Lebrija Formation: Mainly fining-upward sequences of massive medium-gray very thick-bedded conglomeratic sandstones intercalated with reddish gray muddy sandstones and siltstones. The sandstones are lithic to sub-arkosic, fine-to medium-grained. Locally, stringers or thin-bedded pebbles and granules alternations. The gravel fraction is mainly composed of quartz, chert and minor amounts of metamorphics (Figure 18 and Figure 19 (a) and Figure 19 (b).

Figure 18: Rio Lebrija Formation at the Platanalito section. At the base fine-grained, slightly muddy sandstones, overlain in clear and irregular contact by a very thick-bedded fining-upward succession of conglomeratic sandstones grading to medium-grained sandstones. Irregular reactivation surface is present at the topset delimiting an accretionary process.

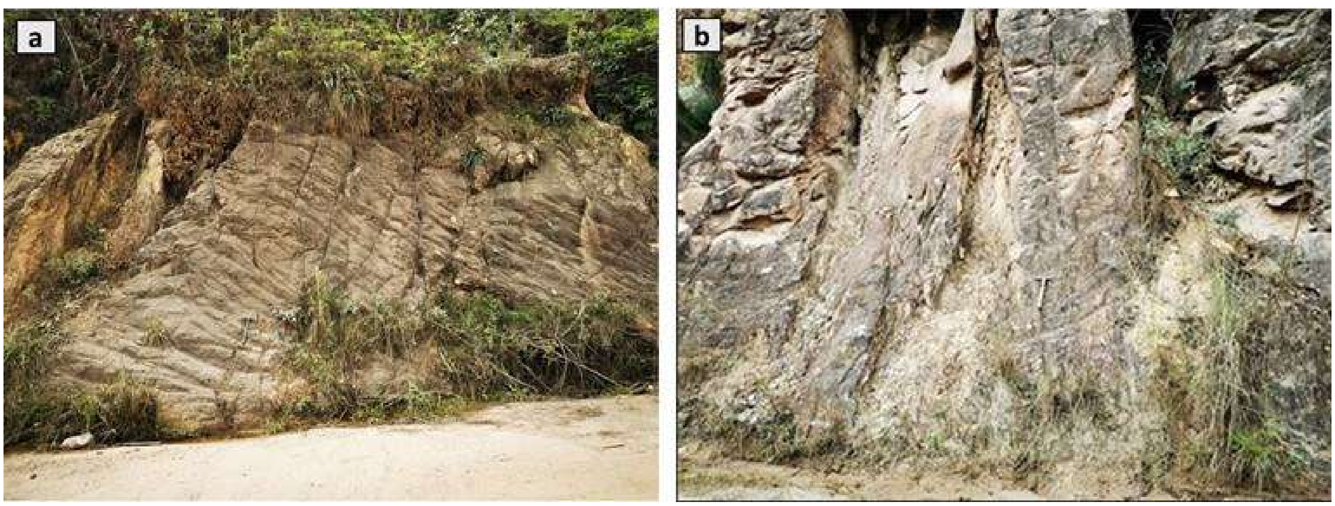

Figure 19: (a) Characteristic very thick-bedded and massive conglomeratic sandstones yellowish gray (5Y7/2) in the uppermost part of the Rio Lebrija Formation at the Tu y Yo High. (b) Some interpositions between the former lithology are the intercalations of thick-bedded slightly conglomeratic sandstones to sandstones, and medium to thick bedded lenticular to wedge-shaped light gray (N7) sandstones. Some of them present thin-bedded planar-laminated fine-grained sandstones varying to moderate reddish brown (10R 4/6) mudstones.

A3.3.2. Los Santos Formation lowermost part - Figure 20 and Figure 21:

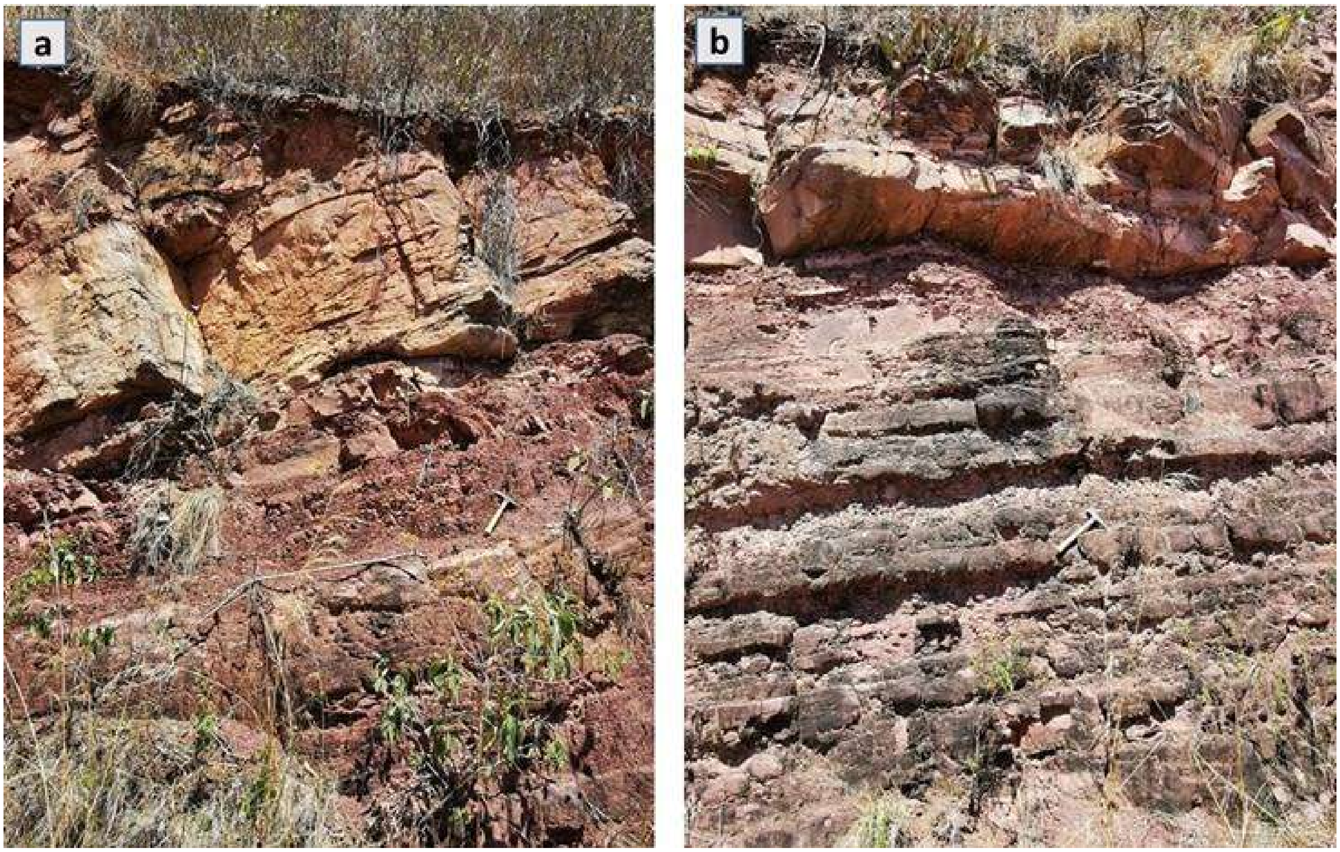

Figure 20: Lower part of the Los Santos Formation (Segment A in the Platanalito stratigraphic section). (a) and (b) photographs are showing roughly a coarsening-upward succession, but incorporates smaller scale fining-upward cycles composed by sandstone, muddy very fine-grained sandstones and mudstones.

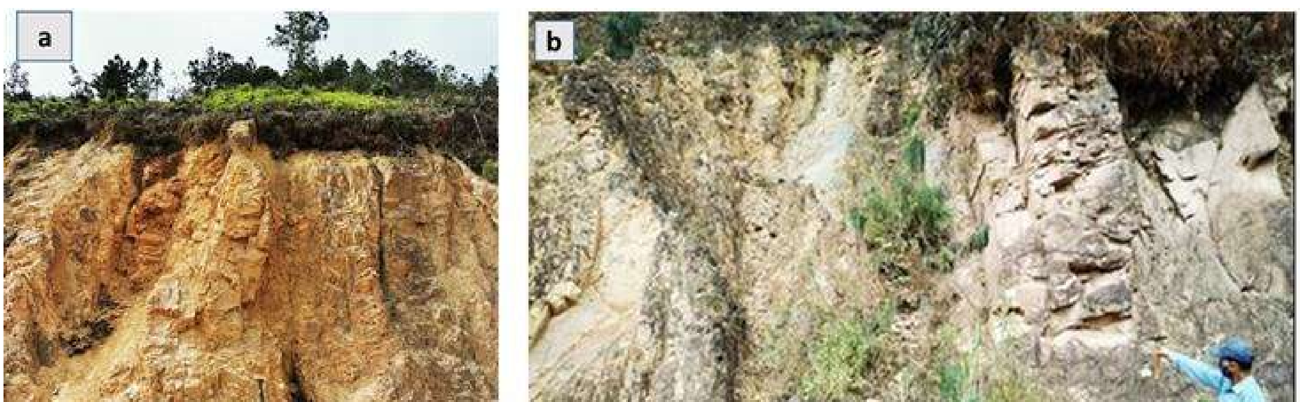

Figure 21: Basal part of the lower Los Santos Formation at the Tu y Yo High. (a) Intercalated pale yellowish orange (10YR 8/6) to grayish orange (10 YR 7/4) medium to thick-bedded fine-medium-grained sandstones and mudstones that overlie the lithologies shown in the photograph b. The photograph identified as (b) is the location where the Lebrija and Los Santos formations are in contact. The field assistant with the hammer tries to show the last intercalated wedge-shaped and massive -bedded conglomeratic sandstones that constitute the top of the Lebrija Formation. At the left of the photograph the succession changes in a sharp manner to greenish gray (5GY 6/1) to pale olive (10 Y 6/2) siltstones to mudstones, locally muddy very fine-grained sandstones that characterize the basal portion of the Los Santos Formation in this place. The boundary between these two formations marks the last ruditic grain-size appearance.

4. Deductions

For rock-bodies with significant gravel content, some key points are deducted:

Lithofacies 1A: The matrix-supported conglomerates that are very persistent at the base of the Los Santos Formation in most of the sections observed are likely to be deposited after an episode of avalanching of the coarse gravel mode, that occur simultaneously with erosion of earlier deposited sand or mud. The sedimentation process is redepositing of two stages. Finally, this deposit is consolidated as a polymictic mixture or as a sediment gravity flow (sensu Middleton & Hampton, 1976). Mass flow conglomerates originate from a variety of debris flows in subaerial settings.

Lithofacies 1B: The clast-supported, coarseness, poor sorted, polymodal gravelly rock-bodies suggest high sediment concentration in the flows and consequently high water discharge. The lithofacies 1B show textural immaturity, suggesting as deposited by surging debris flows following Nemec and Steel (1984) examples. Of the many attributes proposed by Nemec and Steel, (1984) as characteristic features of debris flow deposits, I would like to point out the following:

(1) beds are usually sheet-like, with limited or insignificant basal erosion though often with a highly lenticular overall geometry (La Punta section)

(2) beds are ungraded to well-graded dependent on the internal regime (clast-support mode) of the depositing flow, and the grading type often changes downslope (all of the conglomeratic successions measured in the study area).

(3) beds show no obvious stratification though some may be crudely layered when deposited from surging flows (El Cerro, El Roto examples), and a succession of deposits may be well-bedded due to distinct bed boundaries (El Cerro section, and topset of the El Roto).

(4) beds may range from texturally polymodal to bimodal, and from clast-supported to matrix-supported quite often containing some large, 'outsized' cobbles or boulders (La Punta, El Roto, El Cerro sections).

Additionally, it is necessary to remark:

(a) Disorganized clast fabric may simply reflect short travel distance.

(b) Gravels deposited from ephemeral (flashy) flooding, particularly alluvial fan stream deposits, tend to show greatest textural immaturity.

(c) Mass flows preferentially occur on the upper and middle parts of alluvial fans.

(d) Gravelly mass flows occur in the alluvial environment, particularly on alluvial fans which have a relatively steep slope, small radius, and scarce vegetation (Bull, 1977).

Lithofacies 2: Steel and Thompson (1983) mention that variations from the simple, disorganized beds to the more complex graded and sorted beds, may be explained in terms of position of the sediments in the bars, amount of modification during grain-size segregation or during falling flow stage. Rust (1978) has explained that crudely horizontal stratification or very low-angle strata are mainly formed as longitudinal, or medial bars, whereas grading reflects lateral migration of sediments.

Lithofacies 3: Poorly defined, flat-lying strata have been commonly related to longitudinal bar development, and high-angle cross-strata to transverse bar or bar margin development (Rust, 1972; Smith, 1974). Bluck (1976) has suggested that more organized beds are likely to have accumulated at lower levels on the bar (e.g. the bar margins or tail) where exposure to more prolonged reworking and winnowing could produce a clast-supported framework.

Lithofacies 4: When fluidal gravelly flows occur as at the top of the succession in the Lebrija Highland (El Cerro section), these are named as "sheet-floods" or "stream-floods" (Nemec and Steel, 1984). The horizontal stratified alternation of dominant conglomeratic rocks and sandstones are sometimes referred as deposits of flashy flooding sediments in braided stream environments. The fining-upward facies trend is commonly prominent in successions originating from braided streams.

Lithofacies 5: Tabular-shaped sandstones overlying or as a facies change of gravelly bodies is present at the El Roto section. Many braided stream conglomerates are texturally mature, probably resultant from stronger channelized transport, more continuous runoff, and effective contemporaneous reworking as suggested by Steel and Thompson (1983). Braided stream successions commonly show a fining-upward motif, due to falling flood stage or to gradual abandonment of alluvial tracts.

5. Conclusions

a. An important tectonic pulse is recorded at the base of the Los Santos Formation, developing a subaerial unconformity (SU) in the region located toward east of the Suarez fault and south of the Los Montes fault, covering Paleozoic igneous and metamorphic units and early Jurassic Jordan Formation (Figure 4, Figure 22 (a) and Figure 22 (b).

b. The base of the Los Santos Formation mainly toward east of the Suarez fault, goes from mass-transport and mixed fluvial-braided deposits (see Miall, 1978, Miall, 1985), which were derived from the nearby uplands, whereas the basal facies of the Los Santos Formation south of the Sogamoso fault show a more mature development of the fluvial system because they are in a more distal position with respect to the main source of sediments, such as highland block areas or the ancestral Santander Massif (Figure .22B).

c. Westward of the Suarez fault and south of the Sogamoso fault a correlative conformity (CC) (sensu Haq, 1991) or a paraconformity (sensu Bates and Jackson, 1987) between the basal Los Santos and Rio Lebrija Formation is suggested, based on the contacts and the relationships of different stacking patterns or low data attitude between these two units, respectively.

d. At the north of the study area, in proximity of the Solferino fault and eastward of the Lebrija fault trace there is an important rock-body, dominantly constituted by grayish red to brownish red sedimentary lithoclasts, interpreted as representing an alluvial lithosome (Tambor facies) grading into braided stream currents with possible paleoflow directions to the SSW (Piedra Azul stratigraphic section 2), or receiving this kind of sediments from other place (Jordan Formation uplands in relation to the Bucaramanga fault behavior toward east), in order to explain the lowermost Los Santos Formation in the Pujamanes stratigraphic section 3, containing and appreciable amount of these lithoclasts.

e. The sedimentological development of conglomerate facies is quite similar in all of the stratigraphic sections observed. It begins with poorly calibrated deposits, generally angular to subrounded, disorganized fabric, polymodal, without particle gradation, generally with a significant matrix content, which gradually vary to ordered fabric reflected in a better texture, sorting and compositional stability. These conglomeratic facies gradually change or are intercalated with sandstones and minor shale beds. From this, it is concluded that the grayish red ruditic sediments called Tambor constitute the basal part of the Los Santos Formation in the area of the Lebrija river (stratigraphic column 12) and that gradually and rapidly they vary to thinner layers as in section 2. This means that due to its reduced extension it is called a lithosome. One of the characteristics to interpret its provenance from the Jordan Formation has to do with the fact that they are predominant siltstone grayish red clasts, rounded to subrounded and that it is possible to observe internal stratification in the larger clasts similar to those presenting in the referred unit.

f. As previous researchers mentioned, the overall west dipping basin with extensional block-faulting was filled by a largely unidirectional sediment supply from the neighboring Santander Massif and surrounding areas showing a strong correlation of normal faulting and sedimentological responses. The migration in time and space of dominantly west-dipping normal faults was associated with a gradual shift of the facies and resultant environment.

g. The compartmentalization of the secondary fault system possibly suggests the existence of inhomogeneity in the cover, perhaps due to thickness or facies changes. The initial phases of this tectonic pulse produced a sedimentological record observable in specific areas with diverse characteristics.

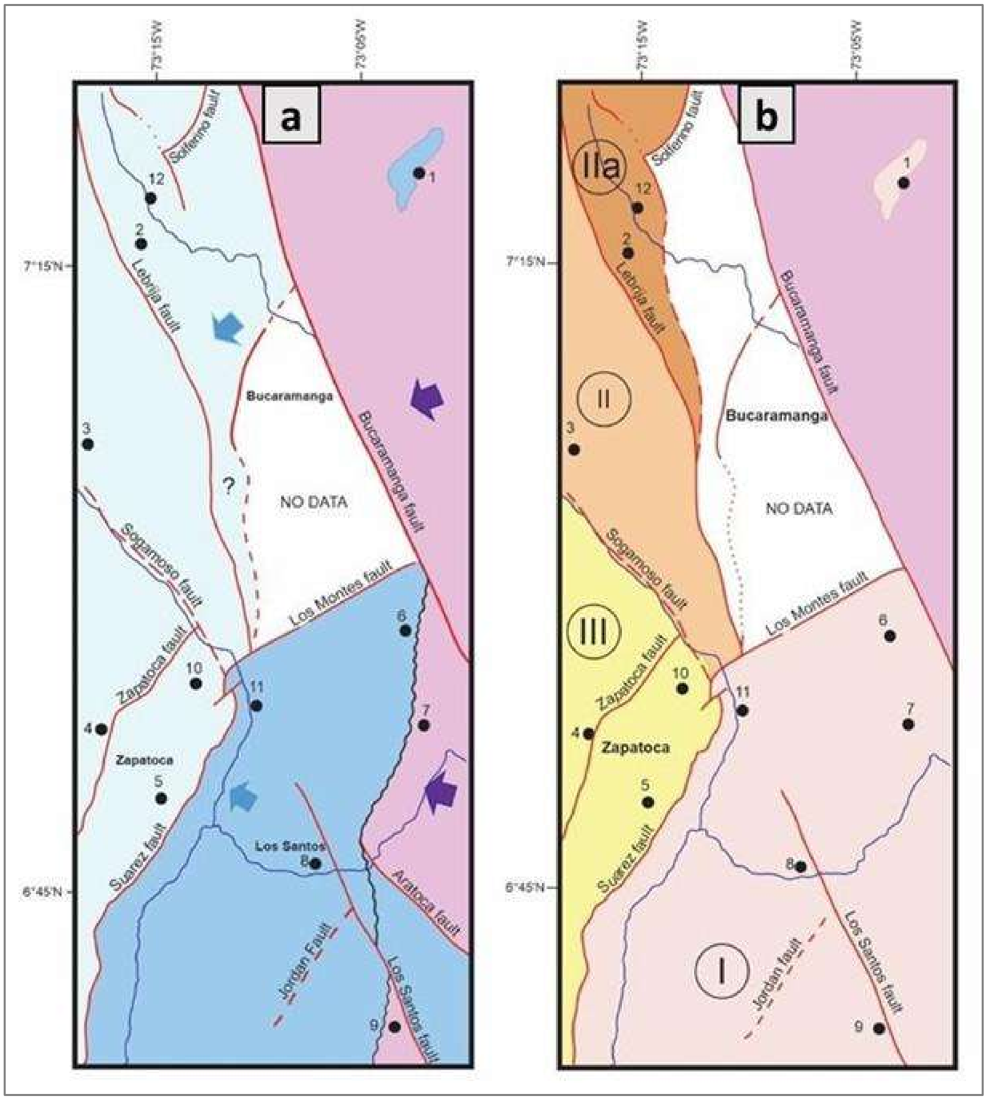

Figure 22. Suggested interpretation of the lowermost Los Santos Formation in the study area. (a) The scheme shows the rock units or formations on which the base of the Los Santos Formation is deposited. Background map color: violet: pre-Jurassic igneous and metamorphic units; dark blue: early Jurassic Jordan Fm; light blue: Rio Lebrija Fm. Arrows are intended to show hypothesized directions of sediment flows. dark violet=Igneous and metamorphic rock units; dark blue: Jordan Formation. (b) Main block-faulting areas that were occupied by the sediments that constituted the segment A of the Los Santos Formation.

h. The block tectonism is the cause of the facial development and architecture of the sediments in latest times of the Rio Lebrija Formation and the subsequent deposition of the lowermost part of the Los Santos Formation (Figure 22 (a) and Figure 22 (b). A result of this is the conformation of depositional domains with specific characteristics, like we observed in this analysis:

- Zone I: Intercalated conglomerates and sandstones and minor lutites, composed of quartz, chert, quartzite and smaller percentages of igneous and metamorphic rocks. The Los Santos Formation rests over an igneous and metamorphic unit's domain or over the Jordan Formation.

- Zone II and IIA: Predominant brownish red sedimentary lithoclasts constitute the framework of conglomerates. This composition is observable in the intercalated sandstones but in minor proportion, as well as an apparent sediment flow direction toward south. The Jordan Formation is suggested as one of the main sediment source origins. The base of Los Santos Formation overlies the Rio Lebrija Formation.

Zone III: Deposition of intercalated sublithic sandstones and mudstones, with no significant conglomerate facies. There is a variable and low percentage of feldspar content. The basal part of the Los Santos Formation is resting upon the Rio Lebrija Formation.

ACKNOWLEDGEMENTS

I am grateful to geologists Jairo Clavijo and Georgina Guzman for many hours in the fieldwork scouting, and geologist Milton Rueda, who was always attentive to my support requirements in the town of Zapatoca. Also, thanks to geologists Steven Diaz and Carlos Mario Alarcon who accompanied me on a visit to the area of Curiti, and the field assistant David Gonzalez, for invaluable support in the outcrop tasks. Finally, I want to thank the peer reviewers of this contribution for useful suggestions in order to improve this paper.

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