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Review article

Revisiting the latest Jurassic-earliest Cretaceous Los Santos Formation, Eastern Cordillera of Colombia

B – A transgressive river mouth deposit in a syntectonic scenario

Revisitando la Formación Los Santos –Jurásico tardío a Cretácico temprano, Cordillera Oriental de Colombia

B- Un depósito transgresivo en la desembocadura de un río, desarrollado en un escenario sintectónico

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ABSTRACT

During the history of research work on the origin of the Los Santos Formation and its significance in the Mesas and Cuestas area (Eastern Cordillera of Colombia), it has been assigned a depositional environment, either as entirely marine or completely fluvial. Based on lithostratigraphic segmentation and facies association analysis, I provide critical clues for the interpretation of depositional environments and particularly relevant to sedimentological assessment changes in the studied succession. This study shows for the lower part of the unit (segment A) the development of alluvial, braided and meandering deposits in the block constituted eastward of the Suarez fault and south of the Los Montes transverse fault. Toward north the succession of the Los Santos appears to be related with the activity of the Lebrija, Solferino and Bucaramanga faults contribution, presenting a possible sediment source from the Jordan Formation. South of the Sogamoso fault and west of the Suarez fault, fluvial deposits, mostly meandering are recorded in segment A. There is some indication of tidal influence in the finer-textured overlying deposit (segment B), interpreted like a central estuary. This widely distributed mud-dominated deposit is cut by a tidal ravinement surface (tRS1), and overlain by a complex of sand-dominated deposits at the mouth of the estuary (segment C), comprising dominant composite dune fields and intertidal sandbars. However, the consolidation process of this deposit at the mouth of the estuary was followed by small regressive and transgressive episodes recorded in segment D, in response to fluctuations in the base level, possibly regulated by tectonic activity.

Keywords: Estuary; transgression; facies association; compound dune; base level.

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RESUMEN

Durante la historia de los trabajos de investigación sobre el origen de la Formación Los Santos y su significado en el área de Mesas y Cuestas (Cordillera Oriental de Colombia), se le ha asignado un ambiente de depósito, ya sea enteramente marino o completamente fluvial. Con base en la segmentación litoestratigráfica y el análisis de asociación de facies, brindó pistas importantes para la interpretación de los ambientes de depósito y particularmente relevantes para evaluar sedimentológicamente los cambios en la sucesión estudiada. Este estudio muestra para la parte inferior de la unidad (segmento A) el desarrollo de depósitos aluviales, trenzados y meandriformes en el bloque constituido al este de la falla del Suárez y al sur de la falla transversal Los Montes. Hacia el norte la sucesión de Los Santos parece estar relacionada con la actividad de las fallas de Lebrija, Solferino y Bucaramanga, presentando una posible fuente de sedimentos de la Formación Jordán. Al sur de la falla de Sogamoso y al oeste de la falla de Suárez, se registran depósitos fluviales, en su mayoría meandriformes, en el segmento A. Hay algunos indicios de influencia de las mareas en el depósito suprayacente de textura más fina (segmento B), interpretado como la parte central de un estuario. Este depósito dominado por lodo ampliamente distribuido está cortado por una superficie de barranco de marea (tRS1) y cubierto por una mezcla de depósitos dominados por arena en la desembocadura del estuario (segmento C), que comprende dunas compuestas dominantes y bancos de arena intermareales. Sin embargo, el proceso de consolidación de este depósito en la desembocadura del estuario fue seguido por pequeños episodios regresivos y transgresivos registrados en el segmento D, en respuesta a fluctuaciones en el nivel de base, posiblemente reguladas por actividad tectónica

Palabras clave: Estuario; transgresión; asociación de facies: dunas compuestas; nivel base

1. INTRODUCTION - WHAT DOES LOS SANTOS FORMATION MEAN IN THE MESAS AND CUESTAS REGION

The objective of the first part, named as A, was to observe and interpret the basal facies of the Los Santos Formation. Its purpose was to understand the significance of the tectonic event that originated them and the sedimentological responses. In this second installment or B, an attempt is made to continue with the overlying succession in order to evaluate the tectonic and stratigraphic relationships before the documented marine incursion in the Cumbre and Rosa Blanca formations. For this purpose, I surveyed and reviewed several stratigraphic columns of the Los Santos Formation, that were key to having an appropriate coverage.

In order to have a clearer definition of the Los Santos Formation and adjacent units from the regional point of view, a simplified geological map was made and is presented in this study (Figure 1). The initial point consisted in a verification of the maps presented by Cediel (1968), Ward et. al. (1973), Velandia (2017) and Moreno-Sanchez (2019). In this map, the rocks that underlie the Los Santos Formation are considered, such as the Paleozoic igneous and metamorphic rock bodies and some sedimentary succession from the Triassic to Lower Jurassic, which were all grouped under the name of pre-Jordan units. Overlying are the Jordan Formation and the Rio Lebrija Formation. The lithologies that overlie the Los Santos Formation are mapped in two units: post-Los Santos and Quaternary deposits.

The Los Santos Formation is a siliciclastic unit that unconformably overlies the igneous-metamorphic rock units of the Santander Massif toward east, or is superposing in slight angular unconformity sedimentary rocks of the Early Jurassic Jordan Formation (Figure 2 (a) and Figure 2 (b). By the other hand, to the west of the Suarez Fault, the Los Santos Formation is found in a paraconformable or correlative conformity contact with the Late Jurassic Rio Lebrija Formation. See Figure 2 (c) and 2 (d). The Los Santos Formation underlies siltstones and sandstones containing small bivalves and gastropods pertaining to the Cumbre Formation, which are superposed by calcareous and shale rocks with the presence of fossils known as the Rosa Blanca Formation, both formations have been dated to Early Cretaceous (Etayo-Serna, 2019).

Throughout the area, the Los Santos Formation is made up of two large rock sandy packages with a muddy interval between these ones (Langenheim, 1959; Julivert, 1963; Julivert *et al.*, 1964). In this study, the lower sandbody-dominated package is called segment A, which is overlain by a muddy-dominated domain, named here as segment B - see Figure 3 (a). Due to mapping reasons, Julivert *et al.*, 1963 grouped these domains as the Lower Los Santos, whereas the upper package is called the Upper Los Santos Formation, corresponding to segments C and D of this study (Figure 3 (b) and Figure 4).

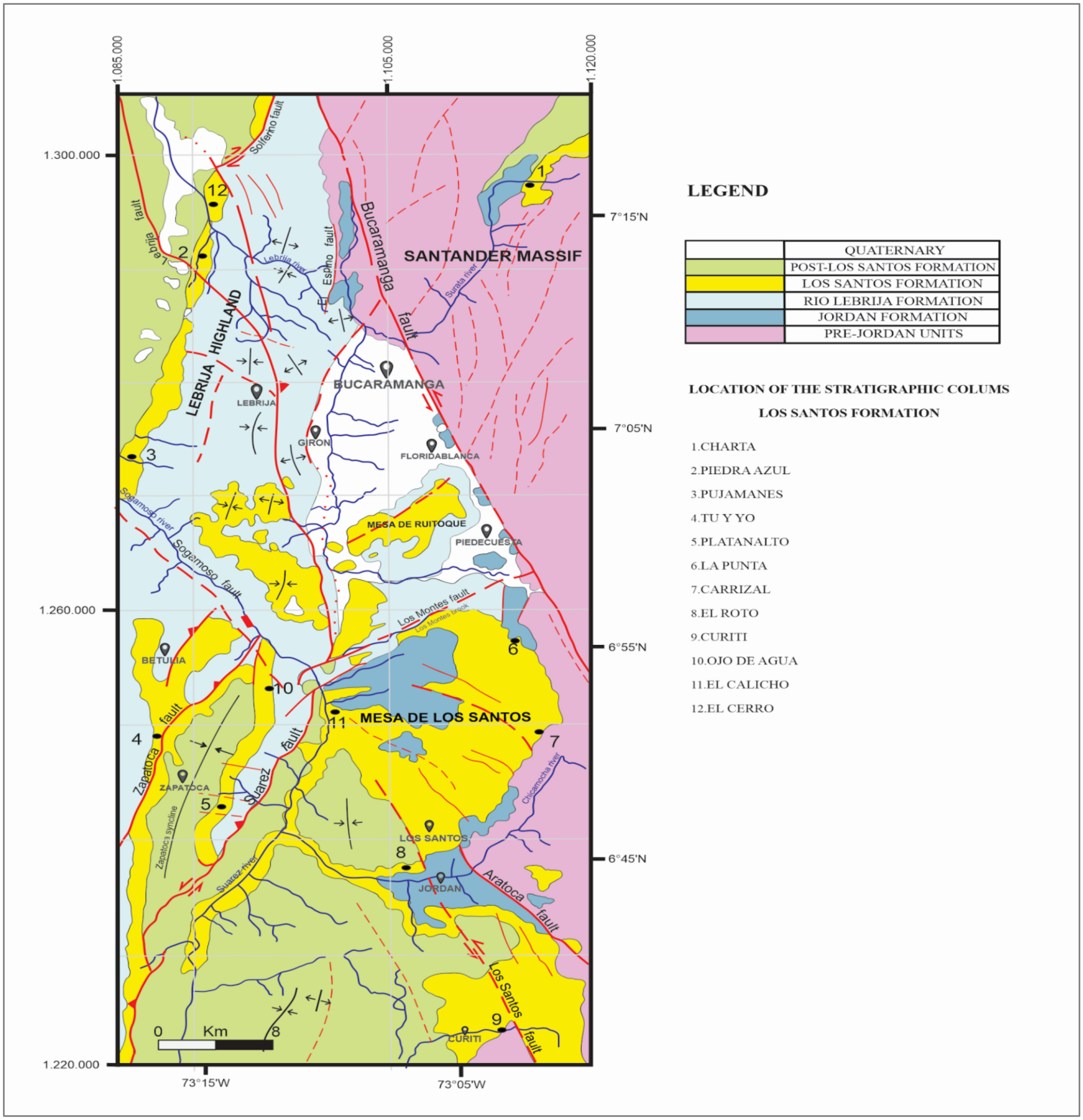

Figure 1. Geological map of the study area based on new data obtained in this revisit exercise, with an important contribution from the works of Cediel (1968), Ward et al. (1973), Velandia (2017) and Moreno-Sanchez (2019).

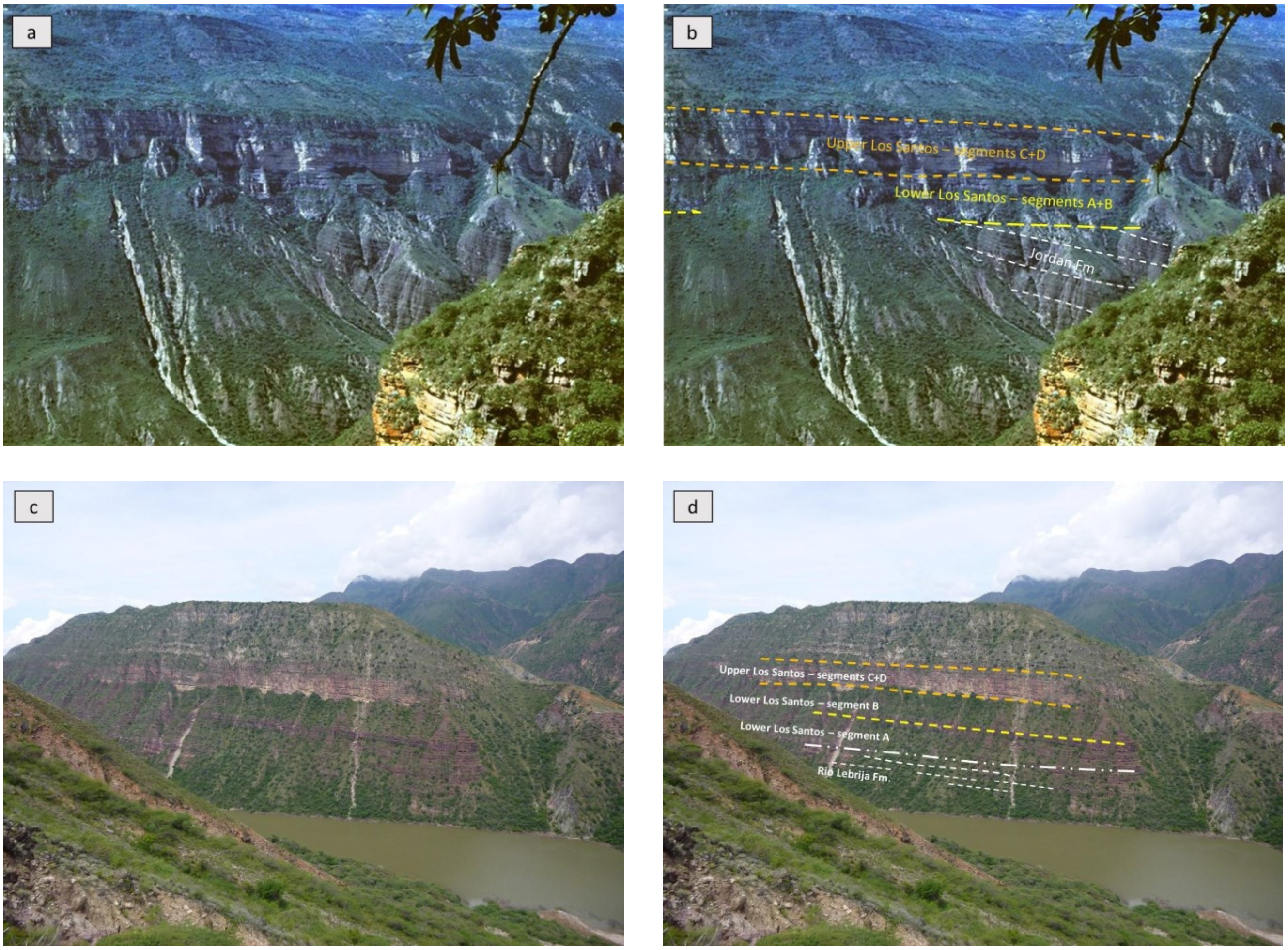

Figure 2. Panoramic views of the Los Santos Formation in two locations: (a) The first panoramic – is looking SE, while (b) is the suggested interpretation. This panoramic is showing the south wall of the Chicamocha river canyon, and was taken from the El Roto trail that is located on the north wall of this canyon (photography taken at 6°44´28´´N and 73°07´35´´W). (c) This photograph is looking to the SW before reaching the Sogamoso river on the road that leads from Giron to Zapatoca (6.89968 N and -73.18066W from Google). (d) It corresponds to the geologic interpretation of the previous panoramic. The interpreted segments of the Los Santos Formation are consistent with the stratigraphic columns performed at the El Roto type locality, and the Platanalito and Ojo de Agua stratigraphic sections, respectively.

This study confirms the subdivision of the Los Santos Formation into 4 segments carried out by Laverde in 1985 (Figure 4). But now a better understanding of the extent of this subdivision is made by using the correlation with other columnar sections of the area.

2. Description of the los santos formation

2.1 Segment A

In part A of this revisit exercise of the Los Santos Formation, the main geological characteristics of segment A, also mentioned as the lowest part of the Lower Los Santos denomination, are exposed in some detail. In this part B we will present a summary of the defined facies, as well as their paleoenvironmental interpretation (Table 1). Some blank spaces mean that these facies have not been identified in this area.

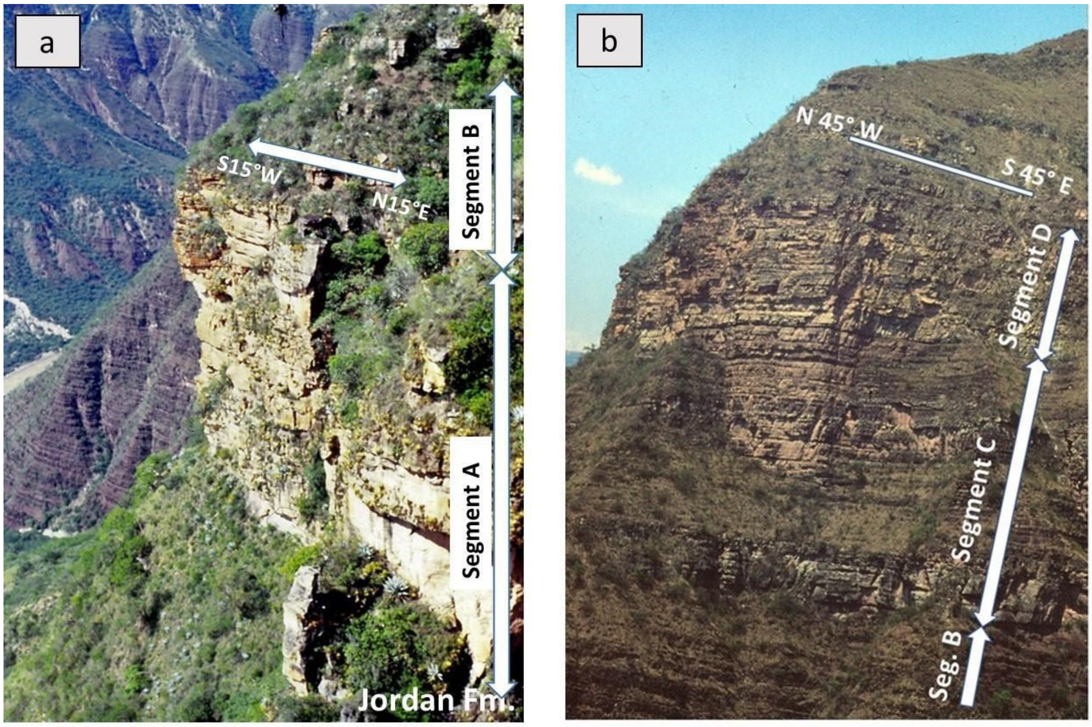

Figure 3. In the El Roto type section, the Los Santos Formation is composed mainly of two very thick-bedded sandstone packages with minor muddy interbeds. The lower Los Santos Formation, made up of Segments A and B. (a) At the bottomset sublithic sandy conglomerates beds and pebble stringers. These lithologies vary from pale yellowish-gray fine to medium-grained sandstones (Segment A) and reddish gray muddy sandstones to sandy shales (Segment B) (Photography taken at 6°44´12´´N and 73°07´22´´W). (b) Upper part of Segment B and the remaining segments C and D. The last two segments constitute the Upper Los Santos Formation and form an outstanding promontory of fine-grained quartzose sandstones recognizable in the Mesas and Cuestas region (Photography taken at 6°44´26´´N and 73°07´12´´W).

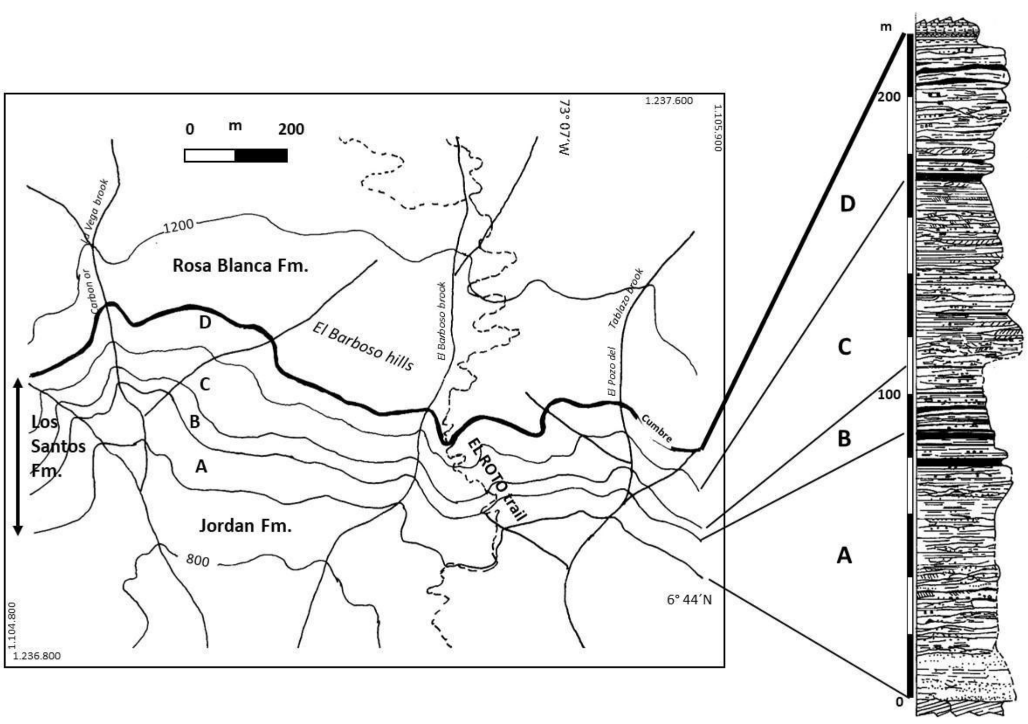

Figure 4. Los Santos Formation geological map and stratigraphic column at the EL Roto type section. Redrawn from Laverde, 1985.

Table 1. Summary of the facies defined for segment A (for more details see part A of the Los Santos Formation revisit exercise)

Lithofacies - East of the Lebrija fault and west of the Solferino fault	**Lithofacies - East of the Suarez fault and south of the Los Montes fault**	**Interpretation**
1A: Simple, disorganized fabric, matrix- supported**,** poorly sorted, polymodal. **1B**: Simple, disorganized fabric, clast- supported, poor sorted, polymodal	**1A:** Simple, disordered fabric, poor sorted, polymodal, matrix-supported sandy conglomerate.	**1A.** Deposition after an episode of avalanching of the coarse gravel mode, that occurs simultaneously with erosion of earlier deposited sand or mud Debris flows in subaerial settings. **1B:** High sediment concentration in the flows and consequently high water discharge.
	2: Simple, crudely organized fabric, massive-bedded and roughly normal or reverse grading	**2**. Probably formed as deposition of longitudinal, or medial bars.
	3: The entire facies association is composed of intercalated matrix and clast-supported conglomerates, conglomeratic sandstones, and sandstones.	3. Longitudinal, transverse bar or bar margin development (Rust, 1972; Smith, 1974).
4A: Horizontally stratified thick-bedded conglomerates and very thick packages of sandstones in alternation. **4B:** Dominantly flat-lying strata of alternated very thick packages of conglomerates and thin to medium-bedded sandstones	**4:** Conglomeratic sandstones horizontally-stratified.	Sheetfloods' or 'streamfloods' (Nemec and Steel, 1984). The horizontal stratified alternation of dominant conglomeratic facies and sandstones (**4A** & **4B**) are interpreted as flashy flooding deposits in braided stream environments.
	5:Sandstone-dominated succession, horizontally-stratified.	Braided stream deposition in a flat area.
Lithofacies - West of the Suarez fault and south of the Sogamoso fault	Intercalated sandstones and mudstones in a fining upward trend: Fluvial meandering deposition in a more distal position with respect to the source area.	

2.2. Segment B:

Sharp contact with the underlying segment A – see Figure 4 and Figure 5 (a). The segment B consists of thick-bedded grayish red (10R 4/2) sandy mudstones to fine-grained muddy sandstones. locally discontinuous undulated to even-parallel internal laminations, intercalated to greenish gray (5GY 6/1) thin-bedded slightly calcareous siltstones and beds of coarsening-upward very fine to fine-grained, slightly muddy sandstones, well rounded, scattered vegetal remnants and some mud cracks are present. Root structures are common, as well as, remnants of disseminated granular caliche. Pipe-shaped ichnofossils parallel to the stratification are scarcely present on some bed surfaces.

A sedimentary structure is found on a flat to slightly wavy arrangement surface, which consists of irregular and sinuously curved ridges, and partially forked. The ridges are separated by depressions measuring up to 2 mm. The structure in general does not present a preferential orientation. The ripple pattern is generally ordered, with the crests orientated almost parallel to one another. These sedimentary structures seem to correspond with the development of *Kinneyia*, which is a class of trace fossil associated with microbial mats (Porada *et al*, 2008). This wrinkle structure has been suggested to form in oscillating flows of water from tidal currents or as storm wave deposits in formerly littoral areas (Porada and Bouougri, 2007). See Figure 5(b) and Figure 5(c).

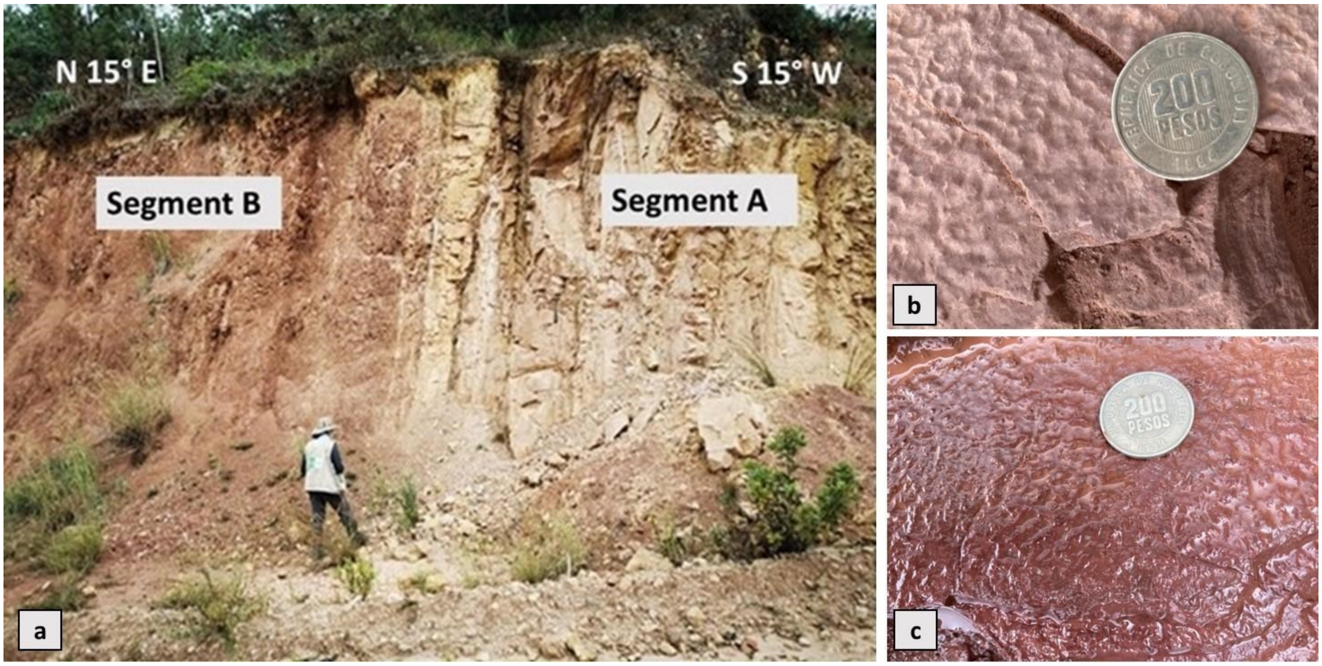

Figure 5. (a) A sharp contact between the sandbody succession at the top of segment A and the massive reddish gray mudstones defined as the bottomset of segment B in the "Tu y Yo '' stratigraphic section. A fluvial bay head delta is a suggested interpretation at the top of segment A. (b) Immediately overlying the top of segment A), is found on the upper bedding planes of very fine-grained sandstones or siltstones an undulating ripple-like structure known as Kinneyia, a class of trace fossil related with the microbial mats that commonly develops in tidal deposits. Location: 6°50´22˝ N and 73°17´39´´W. Down at the right, (c) another wrinkle sedimentary structure located in the segment B of the Platanalito area. Location: 6° 47´40˝ N and 73° 14´20´´W.

2.3. Segment C:

Locally, at the bottom of segment C there is a package (two to seven meters thick) of thin to thick-bedded, lenticular to wedge-shaped, compound and single cross- stratified, fine to medium-grained pinsky gray (5YR 8/1) sandstones that vary laterally to light brownish gray (5YR 6/1) muddy sandstones and siltstones. In the Platanito section, a sandbody shows a significant percentage of oriented intraclasts.

Generally, the very thick package of sandstones composing the segment C, is characterized by thin to very thick-bedded, intercalated tabular-dominated to lenticular and wedge-shaped geometry, fine to medium-grained, well sorted, quartzose grayish pink (5R 8/2) to pale red (10 R 6/2) sandstones. The individual sandstone beds are 20-50 cm thick, and stacked are forming tabular to slightly undulating sets up to 180 cm thick developing a general coarsening and thickening upward trend. Sigmoidal reactivation surfaces, planar cross-stratified, mud-draped low-angle and hummocky cross-stratified are observable. Cross-laminae dips in the same direction as the reactivation surfaces. This succession is dominantly non bioturbated. Syn-sedimentary deformational structures are locally present at the bottomset of this segment. In this large packet of compound dune sandstones there are locally thick laminae to very thin-bedded intercalations of lenticular and wavy-bedded grayish red (10R 4/2) siltstones and mudstones. Figure 6 (a) to 6 (f).

At the upper part of segment C, intercalated thin to thick-bedded, heterolithic, pale yellowish brown (10 YR 6/2) mudstone and yellowish gray (5 Y 7/2) to light greenish gray (5 G 8/1) very fine to fine-grained sandstone, parallel-laminated to symmetrical-ripple foresets and mud draped, forming thick laminae to thin-bedded tabular geometry, some of them wedge-shaped. Contacts are predominantly sharp and slightly undulating.

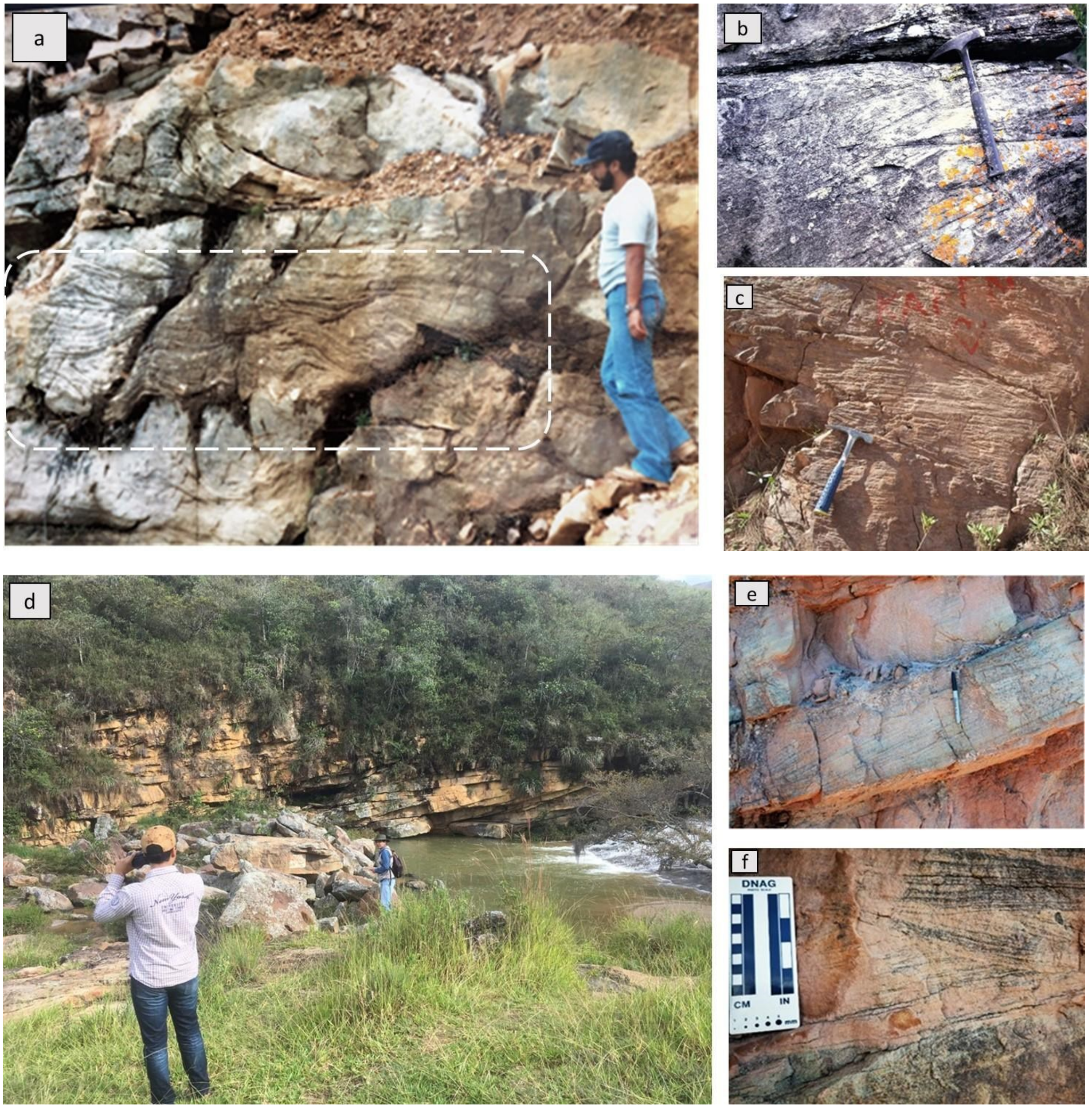

Figure 6. (a) Base of Segment C in the type locality of El Roto. The succession is characterized by thick to very thick bedded fine-grained quartz-arenites affected by synsedimentary deformation. This phenomenon is observed in a continuity of approximately 120 meters. It consists of centimeter to decimeter-thick disharmonic folds. They have curved hinges and are locally disrupted or fragmented. In the beds that are located immediately above and below the section with synsedimentary deformation, no deformation of this type can be seen. Some of its geometries suggest the intervention of liquefaction processes in its genesis. Location: 6°44´24´´N and 73°07´15´´W (b) Lenticular to wedge-shaped, sigmoidal reactivation surfaces forming compound dunes of quartz-rich planar cross- stratified, fine to medium-grained pinsky gray (5YR 8/1) sandstones. Cross-laminae dips in the same direction as the reactivation surfaces. Location: 6°44´25´´N and 73°07´15´´W (c) It is a medium-to thick-bedded package of planar cross-stratified sandstone showing reactivation surfaces bounding planar cross-strata at the Tu y Yo stratigraphic column. (Location: 6.83866 N and -73.289488 W from Google). (d) It corresponds to the Curiti creek outcrop, where a very thick package of medium-bedded, lenticular to wedge-shaped, sinusoidal reactivation surfaces of compound dunes, fine to medium-grained quartzose sandstones are forming the main body of the C segment-Location: (Google: 6.61249 N, -73.04429 W). (e) This one represents a thick bedded, low-angle planar cross-stratified, medium to fine-grained sandstone. The cross-strata is delineated by organic matter and mud drapes becoming tangential at the bottom. (f) Dune with sigmoidal cross-laminae delineated by organic matter and mud drapes, developing concave upward boundary, dissected at the topset by amalgamated organic matter drapes. The last two photographs were taken at the Platanalito stratigraphic section, located at 6°47´40´´N and 73°14´20´´W.

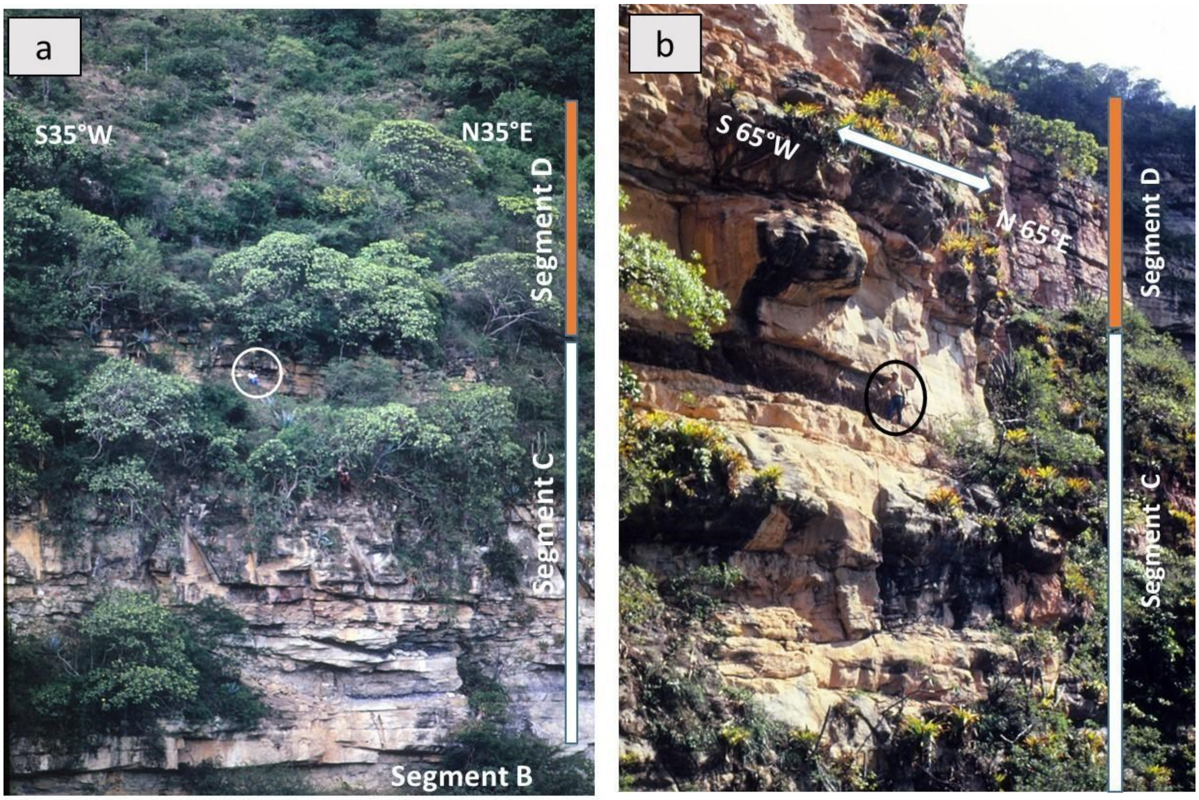

Figure 7. Panoramic views of the Los Santos Formation at the El Roto type section. (a) It refers to the succession from the top of Segment B, passing through the Segment C and the covered Segment D at the top of the unit. The segments C and D constitute the Upper Los Santos Formation. (b) This photograph shows some bed geometries of part of the segments C and D. Scale is given by a field assistant enclosed in a circle-shaped form.

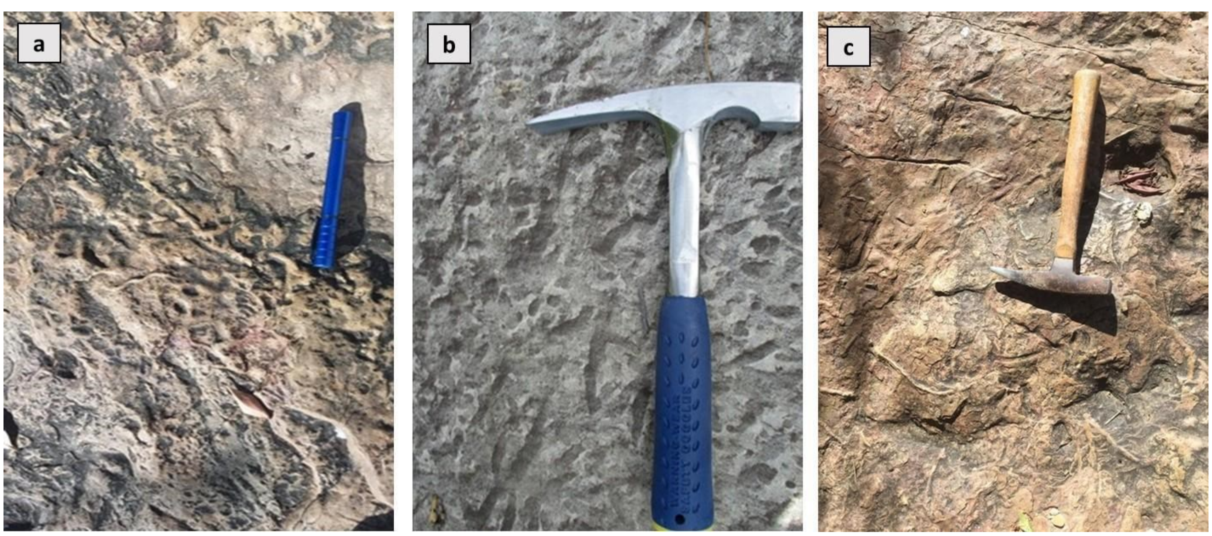

Figure 8. Trace fossils at the top of the Los Santos Formation. (a) This is a photograph taken at the El Roto stratigraphic column (6°44´29´´N and 73°07´16´´W). (b) It corresponds to the La Lajita brook, near the Tu y Yo stratigraphic section. (c) At the Curiti brook, the sandbodies at the top of the Los Santos Formation show excellent outcrops of trace fossils (6.607198 N and -73.046650 W from Google). All these ichnofossils are interpreted as representing Scoyenia ichnofacies (Etayo-Serna, 2019).

2.4. Segment D:

At the type locality (Figure 4 and Figure 7), there are intercalated very thick-bedded sandstones and medium-thick-bedded mudstones. In the sandbody portion there are sigmoidal-shaped surfaces which are delineated by sharp and undulating contacts, some of them erosive-based, low-angle planar cross-stratification fine-grained sandstones, well-sorted, with local mud drapes and interbeds of thick laminae to thin-bedded greenish gray mudstones. At the upper part, medium to thick bedded composed dunes and single dunes, 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 (Figure 8).

2.5. Cumbre Formation

The Cumbre Formation overlies the Los Santos Formation in a rapid transitional contact in most of the places. Because the lithologies that make up the Cumbre Formation in the Mesas and Cuestas area appear as a fairly thin unit (less than 15 meters thick), with new facies elements, some authors (Zamarreño de Julivert, 1963, among others) have considered as a transit facies or rapid passage lithologies from the Los Santos Formation towards the overlying unit, the Rosa Blanca Formation.

The Cumbre Formation consists of coarsening upward succession of completely bioturbated (BI= 5-6) greenish gray (5GY 6/1) massive siltstones overlying the sandbodies of the segment D in predominant transitional contact. The upper half is composed by a medium to thick-bedded medium-grained sandstone which is overlain by thin to very thick-bedded intercalations of very fine-fine-grained muddy and fossiliferous siltstones. A dolomitic sandstone is observable at the topset. Tabular geometry, internal stratification is plane-parallel-laminated. Trace fossils burrows up to 4mm in diameter are filled with oxides of bifurcated cylindrical shapes and greenish-gray root remnants towards the top. The highly bioturbated dolomitic sandstone is identified by the presence of phosphatized micro-gastropods, disarticulated shells of small suspensive bivalves, echinoderm spicules traces.

3. Facies interpretation

3.1. Segment A:

For a more detailed facies description and interpretation that make up Segment A, please refer to Part A of this Los Santos Formation revisit exercise.

3.2. Segment B:

Sandy mudstones and muddy sandstones with plant remains may characterize deposits in flood plain areas. The root traces indicate that soil formation processes were taking place during the deposit of these sediments. The great predominance of tabular geometry, distinctive horizontal stratification, is indicative of a very flat paleo-topography, possibly in a coastal plain, or in a quiet lagoon zone due to the sediments deposited there. The intercalations of fine-grained quartzose sandstone with the presence of double mud drapes, the presence of Kinneyia structures suggest deposits with some tidal influence and record littoral deposition.

Based on the previous considerations, Segment B is the lithological record of an area where materials contributed by river currents from the continent (Segment A) located towards the uplands or hinterlands to the east, converge with those from a coastal area located to the west in a relatively flat area. According to this, it is suggested that Segment B corresponds to a central estuary or estuary basin (sensu Allen and Posamentier, 1994; Dalrymple and Choi, 2007) among others.

3.3. Segment C:

The segment C constitutes an amalgamated and progradational compound dune package complex (Desjardins et al, 2011), or large compound tidal dunes (Olariu et al, 2012). The cross strata that formed by simple superimposed dunes mostly dip in the same direction as the inclined master bedding planes within the compound dune, forming a forward-accretion architecture.

The base of segment C constitutes a major erosional surface, incising into the older inner surface of estuarine mudstone-dominated segment B. This net, incisive, erosive-appearing surface at the base of segment C results from tidal scouring at the mouth of the estuary and is known as the tidal ravinement surface (Allen, 1991). The base of the segment C with the presence of large bedforms, is interpreted as evidence of increased sediment supply due to the migration of larger bedforms that marks the consolidation of the first transgressive ravinement surface (tRS1) of the estuarine deposits.

Most of the segment C records the migration of medium to large compound dunes under strong unidirectional currents within a compound dune field in a subtidal setting. The absence of significant mudstone beds intercalated into the sandstone packages in the lower part of segment C reflects high-energy conditions typical of shallow subtidal settings (i.e., Desjardins et al, 2011).

The sediments of segment C were probably provided by wave erosion of older nearshore marine and dune deposits from the adjacent coasts located toward west as accumulated as estuary-mouth shallow subtidal compound dune fields and sheet sands (sensu Desjardins et al., 2011).

In other terms, a marine sand body such as that represented by Segment C in this study consists of a core of transgressive subtidal shoals and/or washover deposits on which is built a "estuary mouth sand plug" (sensu Boyd et al., 2006) or a barrier cut by one or more tidal inlets (Roy et al., 1980). The segment C in general suggests a dominant landward progradational flood tidal deposits (i.e., Dalrymple, 2010). Flood and ebb tidal deposits are known as subtidal to supratidal dunes.

3.4. Segment D:

The facies associations that make up the segment D may represent the record of intermittence of transgressive and regressive episodes at the mouth of the river system. The toeset of sandbodies suggest again the locally migration of compound dunes on the shallow subtidal setting forming smaller compound dune field deposits where the main components are sigmoidal reactivation surfaces, low-angle cross-stratified sandstone beds which converge down-dip tangentially and accreting vertically. Consequently, these compound dunes migrate by forward accretion in the direction of the local predominant flow. The counterpart corresponds to the deposits of reddish mudstones with plant remains that are intercalated with other sandbodies present.

Both, tabular-sheet-like bedforms and canaliform bodies show lateral accretion surfaces, suggesting the presence of a tidal bar complex above the compound dune. The geometry, texture and biogenic-content of the uppermost sandbodies of segment D seems to represent distal tidal bar bodies reaching the shallow platform. According to Desjardins et al., 2011, tidal bars migrate by means of lateral accretion in association with channels. Tidal bars tend to occur in onshore areas bounded by channels, or in brackish-water marginal-marine settings. Olariu et al., 2012 consider that such sand bars are common in the mouths of rivers in the outer part of estuaries.

4. An approach to dating the Los Santos Formation

Approaches for dating the continental sequences spanning the Jurassic to early Cretaceous rocks in the study area have resulted in a low-resolution chronologic data (i.e., Brueckner, 1954; Langenheim, 1961; Cediel, 1968; Pons, 1982; Etayo-Serna and Rodriguez, 1985; Cooper, 1995; Horton et al., 2015) due to poor fossil preservation, mainly plant remnants. Consequently, most sedimentary strata pertaining to Lebrija Formation are inferred to be of Jurassic age, whereas the Los Santos Formation has been argued to be the base of the Cretaceous due to the absence of unconformities with the overlying Berriasian Cumbre Formation (Etayo-Serna ,2019), Etayo-Serna and Guzman-Ospitia (2019).

A composite magnetic polarity stratigraphy was performed by Jimenez et al., 2021 based on 199 samples from the Giron Group in a section spanning the 518 m of upper part of the Lebrija Formation and the 299 m of the Los Santos Formation in the Tu y Yo High (Cuchilla del Ramo Section or CRS), located in the eastern limb of the Los Yariguíes anticlinorium. Normal-polarity (N1 to N26) and reverse-polarity (R1 to R26) magnetozones were analyzed, using two approaches (deterministic and stochastic modeling) to try defining a coherent magnetic polarity age, because they were not possible to define a unique model of magnetic polarity age for the stratigraphic section (Figure 9 (b).

Although Jimenez et al., 2021 mentioned some limitations in the deterministic model they preferred this model over the stochastic model because during the correlation process, they involved specific information about the interpreted ages of the Los Santos, Cumbre, and Rosablanca Formations by different researchers. Based on the compiled magnetic polarity succession of the Giron Group, compared with the Geomagnetic Polarity Time Scale (GPTS) after Ogg et al., (2016), the estimated age for the Lebrija Formation goes from ca. 157 to 148 Ma, corresponding to early Kimmeridgian to early Tithonian, while the age of the Los Santos Formation is inferred from 148 to ca. 139 Ma., and goes from early Tithonian to early Valanginian. From this data, Jimenez et al., 2021 conclude that the Jurassic-Cretaceous boundary is thus likely located within the Los Santos Formation, implying that this lithostratigraphic unit is older than previous age estimates.

Now, if we take into account that in the present Los Santos Formation revisiting exercise, the Tu y Yo stratigraphic column before published by Laverde and Clavijo (1985) has been adjusted and modified based in a more detailed correlation (Figure 9 (a), and that the base of the Los Santos Formation is located below what Jimenez et al., 2021 have shown, some age estimates are suggested: The succession called A, whose origin is eminently fluvial, and the muddy succession called Segment B seem to correspond to the latest Jurassic (Tithonian), while the succession of dominantly quartzose sandstones called segment C, which the base is interpreted as a surface of tidal ravinement seem to constitutes the first entry of the sea in the Cretaceous (Berriasian).

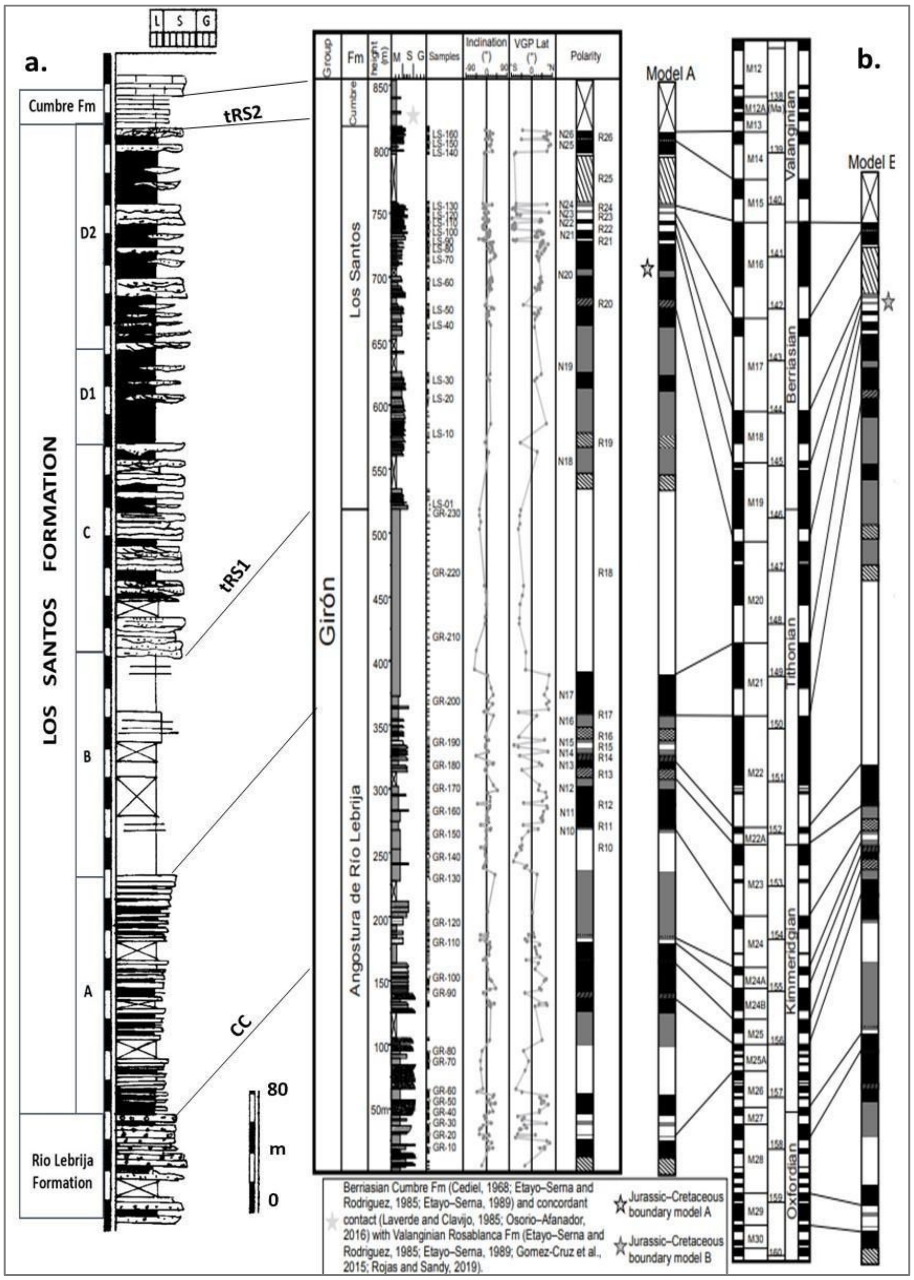

Figure 9. In order to obtain updated data about the age of the Los Santos Formation, this correlation scheme is presented. (a) Stratigraphic column of the Los Santos Formation surveyed at the Tu y Yo High, east flank of the Yariguíes anticlinorium, which was revised and modified from that presented by Laverde and Clavijo (1985). (b) Stratigraphic column presented by Jimenez et al., 2021 from a previous survey carried out by Osorio-Afanador (2016) at the same site and referred to as the Cuchilla del Ramo Section (CRS). Note that although there are differences in the delimitation of the Rio Lebrija and Los Santos formations, the lower part of the latter still belongs to the Late Jurassic and that the Earliest Cretaceous probably corresponds with the base of segment C of the present research where a tidal ravinement surface (tRS1) is interpreted and followed by transgressive compound dunes deposits.

5. The correlation of stratigraphic sections

The correlation of stratigraphic columns is a tool that allows not only to observe the different changes in the determined facies, but also provides tools to determine the relationships between tectonics and sedimentation. This work includes correlations of all stratigraphic sections evaluated in all possible directions (Figure 10 to Figure 21). The top of segment B and the top of the D2 interval of segment D were taken as the datum's for the respective correlations.

The first step was the recognition of major stratigraphic surfaces, such as all those successions in contact with igneous or metamorphic rocks of the Santander Massif, or those that are in a nonconformity relationship on older rocks (see for example the contact Los Santos Fm. / Jordan Fm.) Following the Catuneanu (2006) nomenclature, this kind of stratigraphic surface named as subaerial unconformity (SU) implies a stratigraphic hiatus in the sedimentary rock record separating strata that are not related genetically, defining an abrupt shift of facies toward the basin. Another criterion for defining a subaerial unconformity, is to identify the base of coarse-grained valley-fill deposits, which may directly overlie finer-grained strata of different formation-age (*i.e*., Segment A of the Los Santos Formation resting upon Jordan Formation).

A second type of contact defined in this study is related to the facies contacts in fully fluvial successions, where abrupt shifts in fluvial styles are recorded across the contacts. In such cases, the contrast in fluvial styles reflects a decrease in fluvial energy levels associated with a shift of facies toward basin (for instances, top of the Rio Lebrija Formation and base of the segment A of the Los Santos Formation west of the Suarez fault and south of the Sogamoso fault stratigraphic sections 4, 5 and 10).

However, as in the contact between the Rio Lebrija and Los Santos formations, a stratigraphic hiatus has not been determined. That is to say, the absence of a time interval between the deposit of both units, due to not having a non-conformity relationship, or due to the absence of fossils that allow its dating. Then, there are two possibilities of defining this contact: 1). Estimating the possibility of considering it to be a paraconformity *sensu* Bates and Jackson (1987), or 2). Considering it as a correlative conformity (CC) *sensu* Haq, 1991. In this study the second option was chosen.

As a result, the main tidal- ravinement surface (tRS1) is placed at the contact between central estuary muds below, and the estuary-mouth complex above. The facies above are always shallow-marine (Catuneanu, 2006). In a most complete scenario, where most estuarine facies are preserved, the tidal-ravinement surface occurs at the contact between central estuary muds below and estuary mouth sands above (Allen and Posamentier, 1993). A probable second tidal ravinement surface (tRS2) is suggested to be located at the bottom of the fossiliferous siltstones and mudstones in the Cumbre Formation. Transgressive ravinement surfaces are scours cut by tides and/or waves during the landward shift of the shoreline.

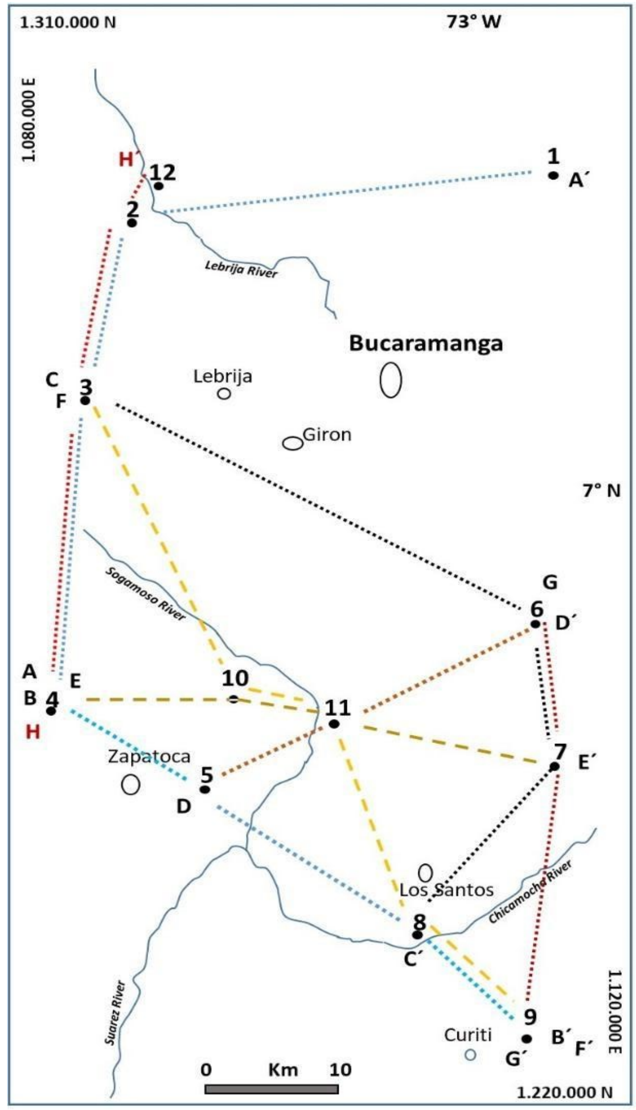

Figure 10. Location map of the correlated stratigraphic sections.

Another important surface due to its significance in understanding the sedimentological development of the Los Santos Formation is the one where a regional widespread package of quartzose sandstones belonging to Segment C rest on a reddish muddy succession of the segment B. This stratigraphic surface is interpreted as the first surface of marine erosion or tidal ravinement surface (tRS1).

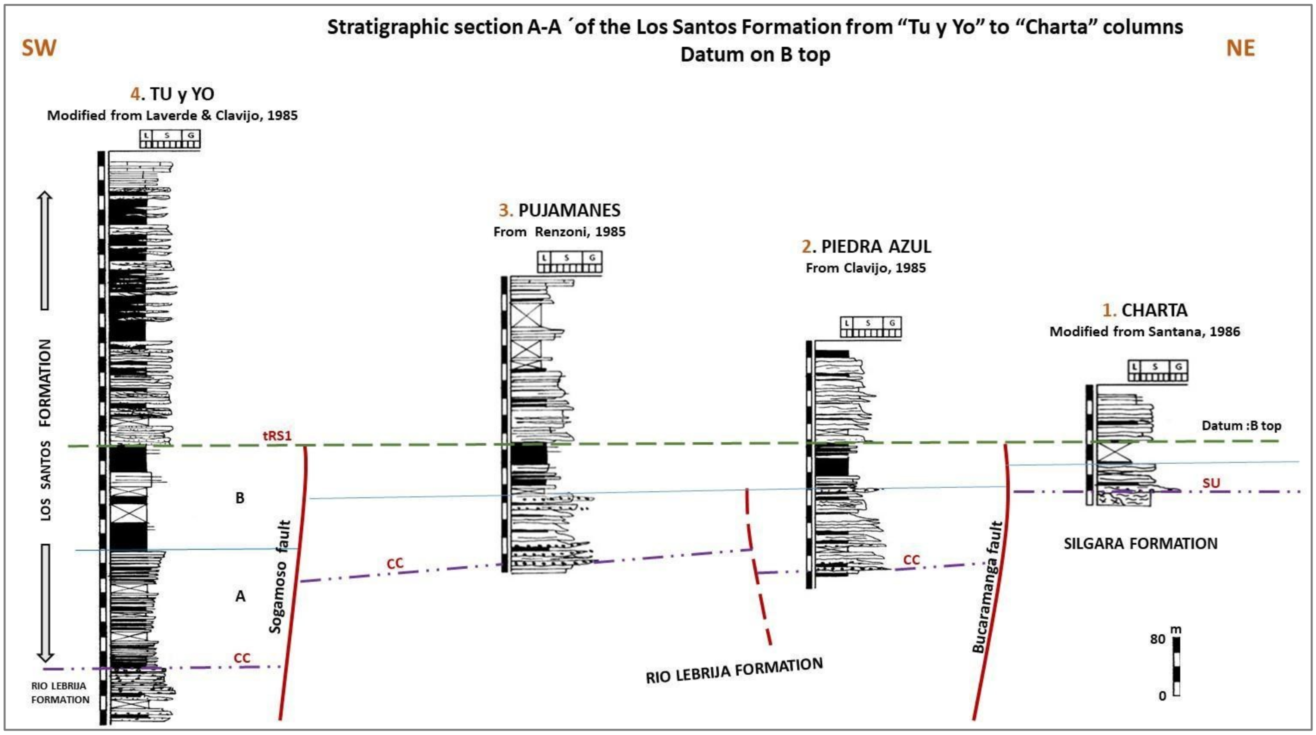

Figure 11. Stratigraphic section A-A´ from "Tu y Yo", Pujamanes, Piedra Azul and Charta measured columns. Datum on B top.

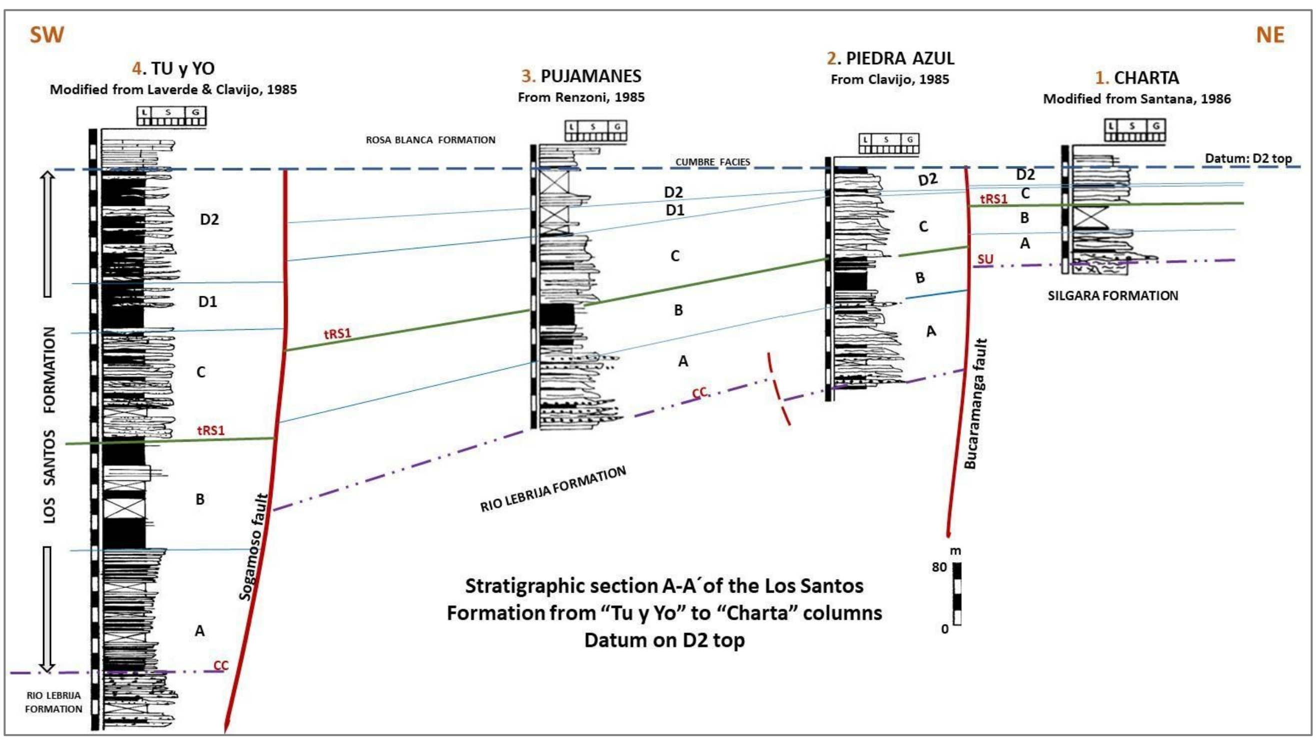

Figure 12. Stratigraphic section A-A´ from "Tu y Yo", Pujamanes, Piedra Azul and Charta measured columns. Datum on D2 top.

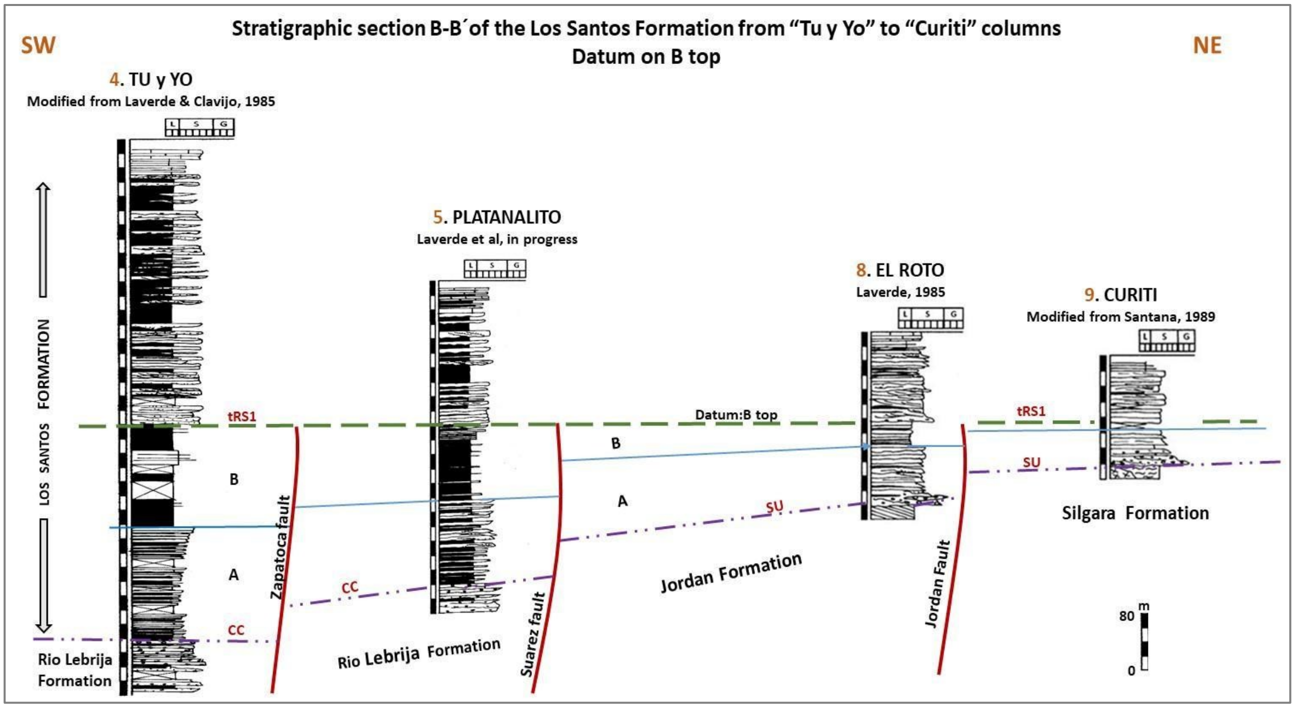

Figure 13. Stratigraphic section B-B´ from "Tu y Yo", Platanalito, El Roto and Curiti measured columns. Datum on B top.

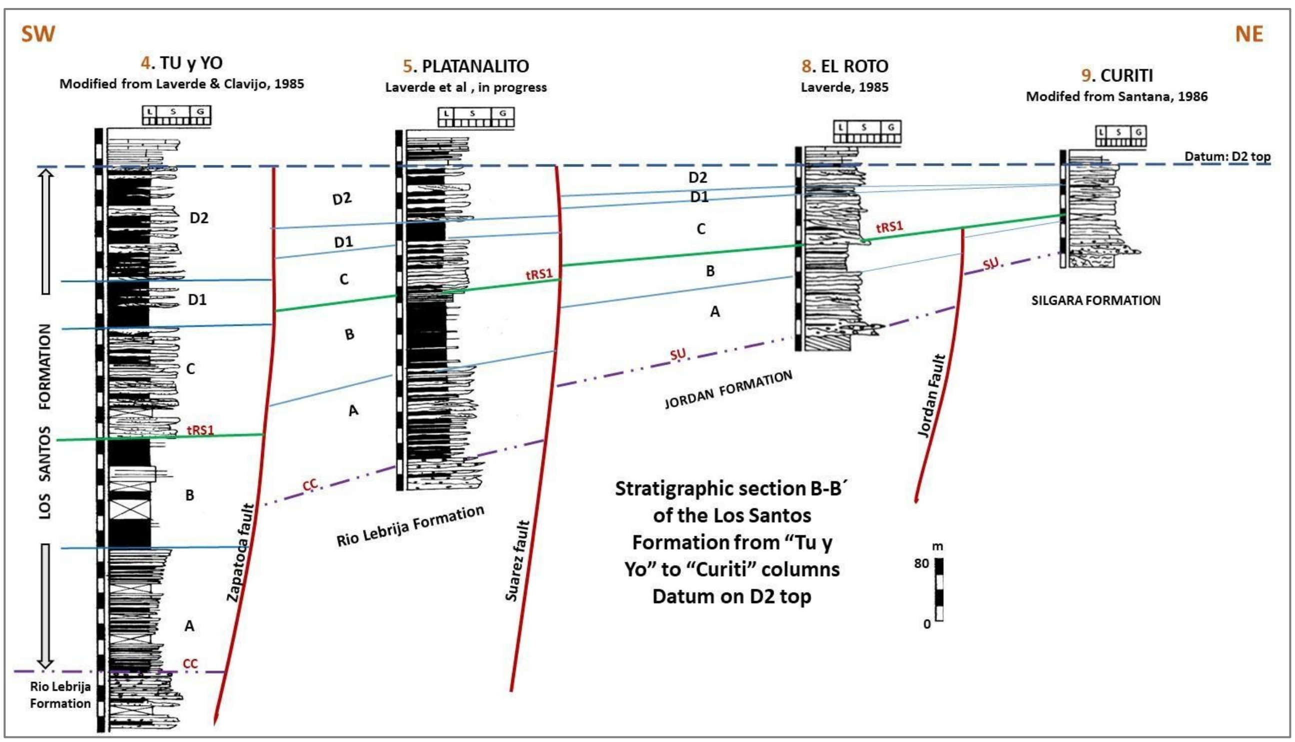

Figure 14. Stratigraphic section B-B´ from "Tu y Yo '', Platanalito, El Roto and Curiti measured columns. Datum on D2 top.

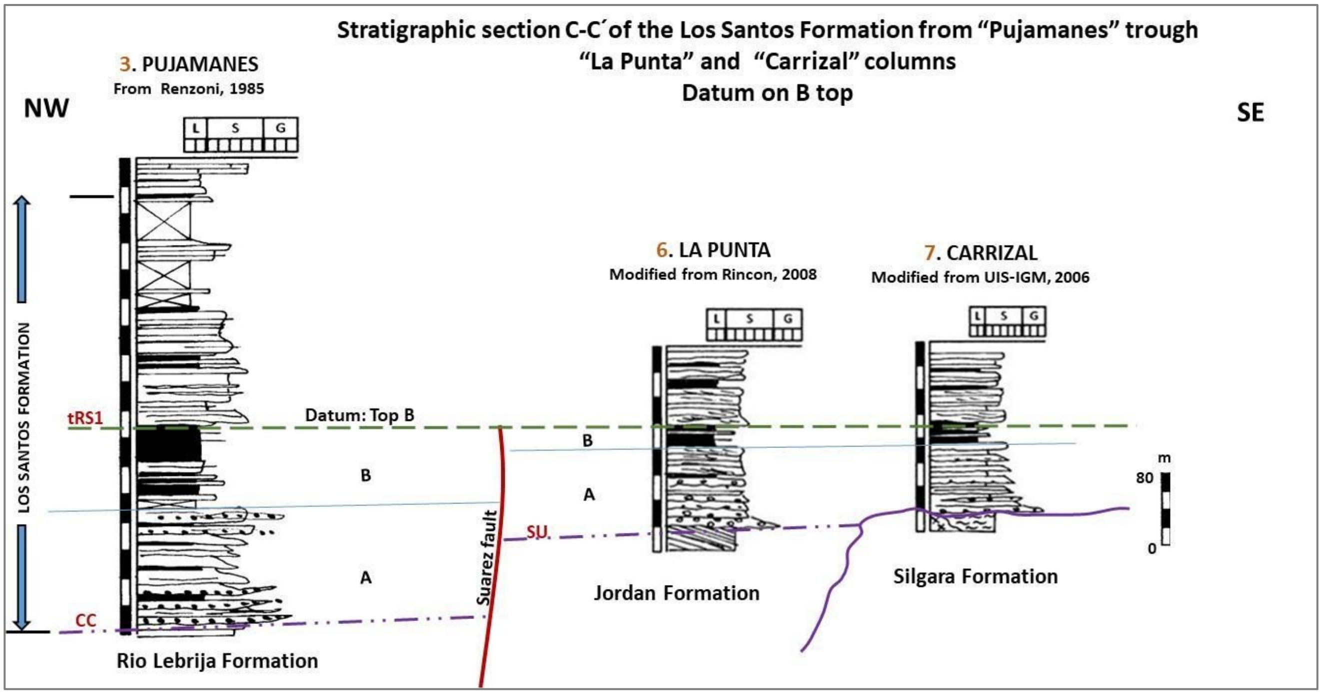

Figure 15. Stratigraphic section C-C´ from Pujamanes, La Punta, Carrizal and El Roto measured columns. Datum on B top.

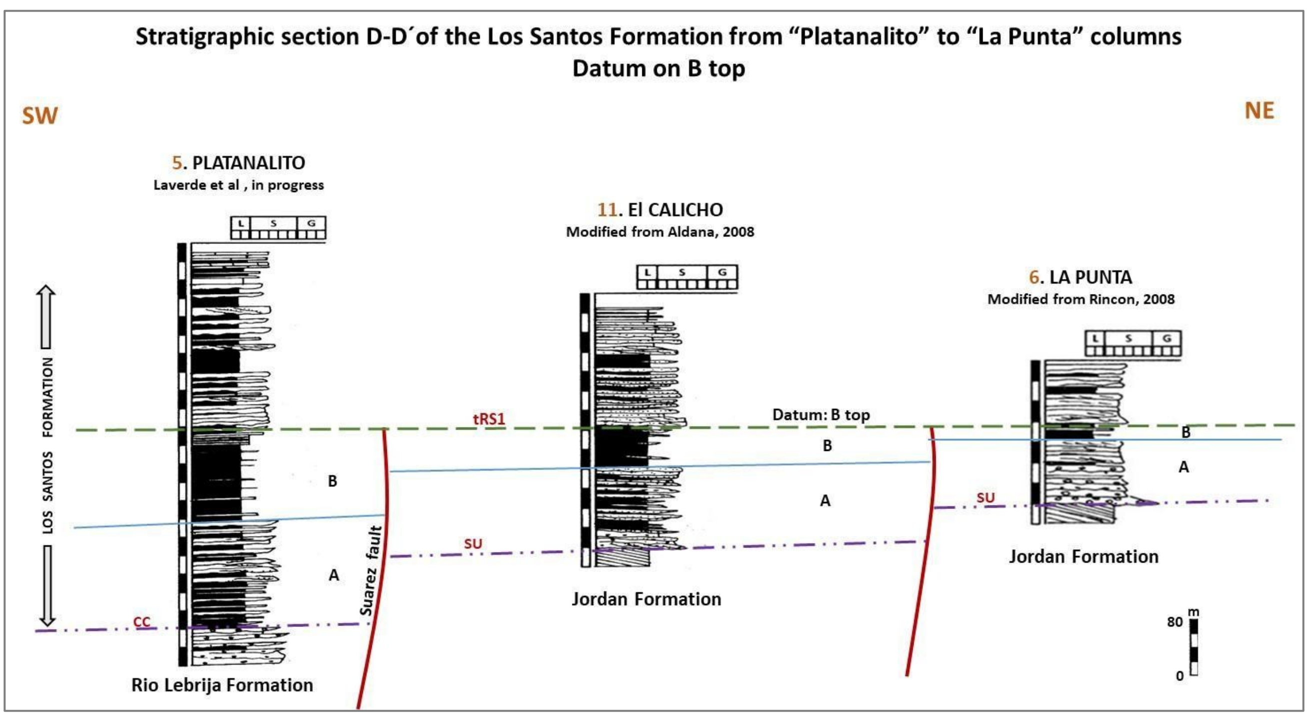

Figure 16. Stratigraphic section D-D´ from Platanalito, El Calicho and La Punta measured columns. Datum on B top.

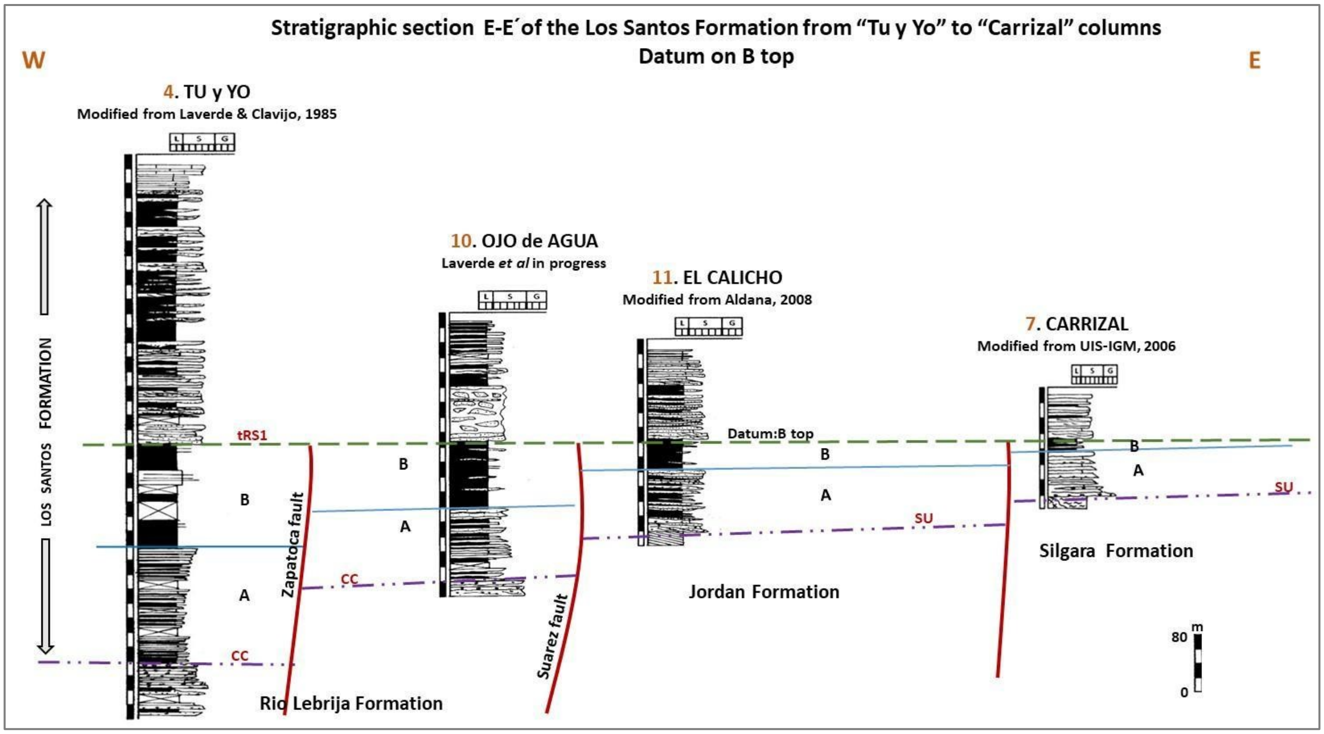

Figure 17. Stratigraphic section E-E´ from Tu y Yo, Ojo de Agua, El Calicho and Carrizal measured columns. Datum on B top.

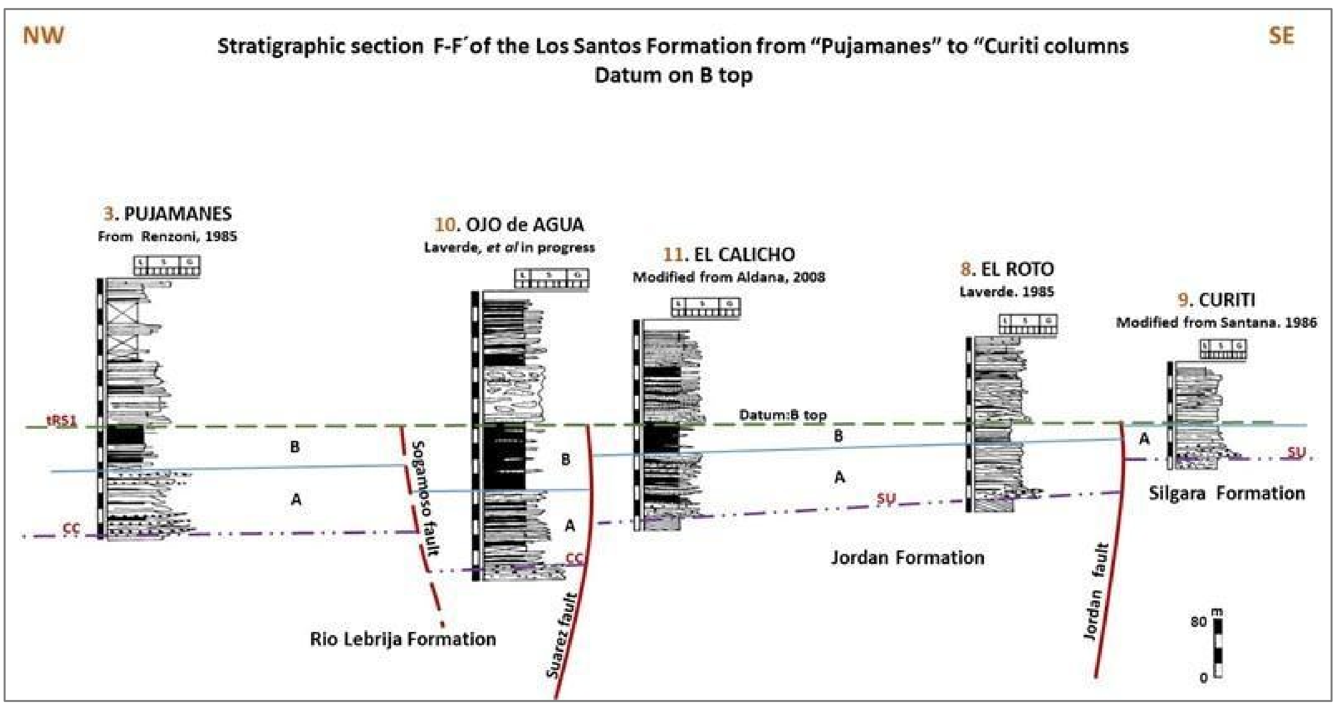

Figure 18. Stratigraphic section F-F´ from Pujamanes, Ojo de Agua, El Calicho, El Roto and Curiti measured columns. Datum on B top.

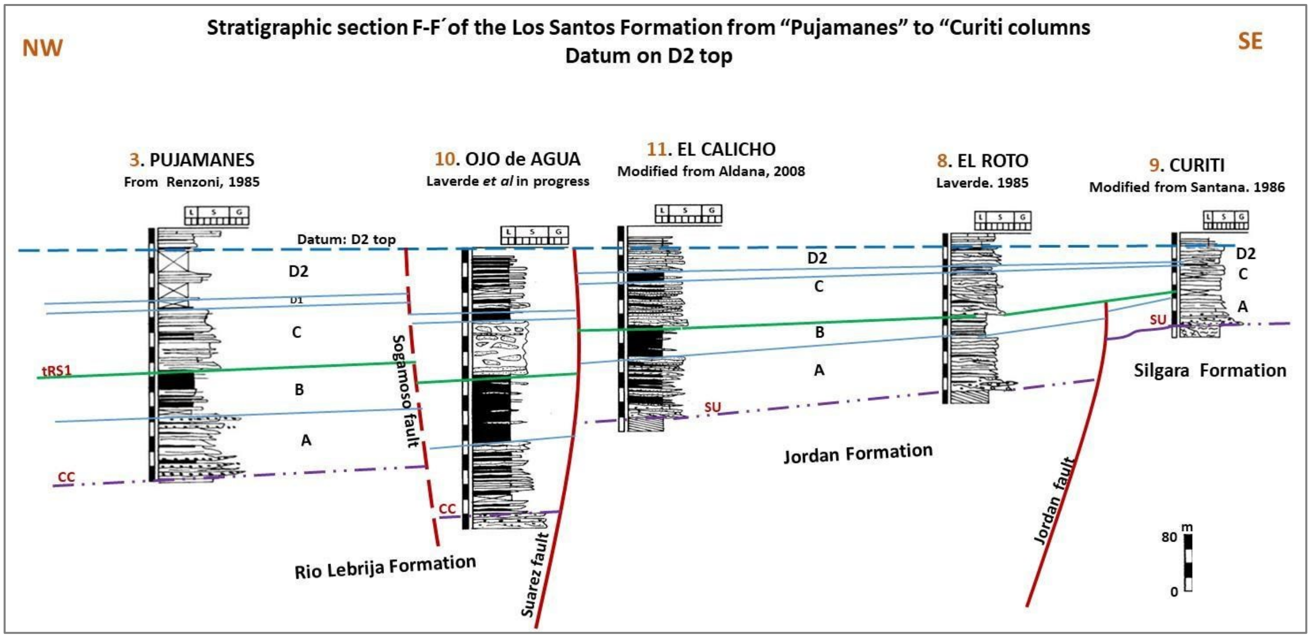

Figure 19. Stratigraphic section F-F´ from Pujamanes, Ojo de Agua, El Calicho, El Roto and Curiti measured columns. Datum on D2 top.

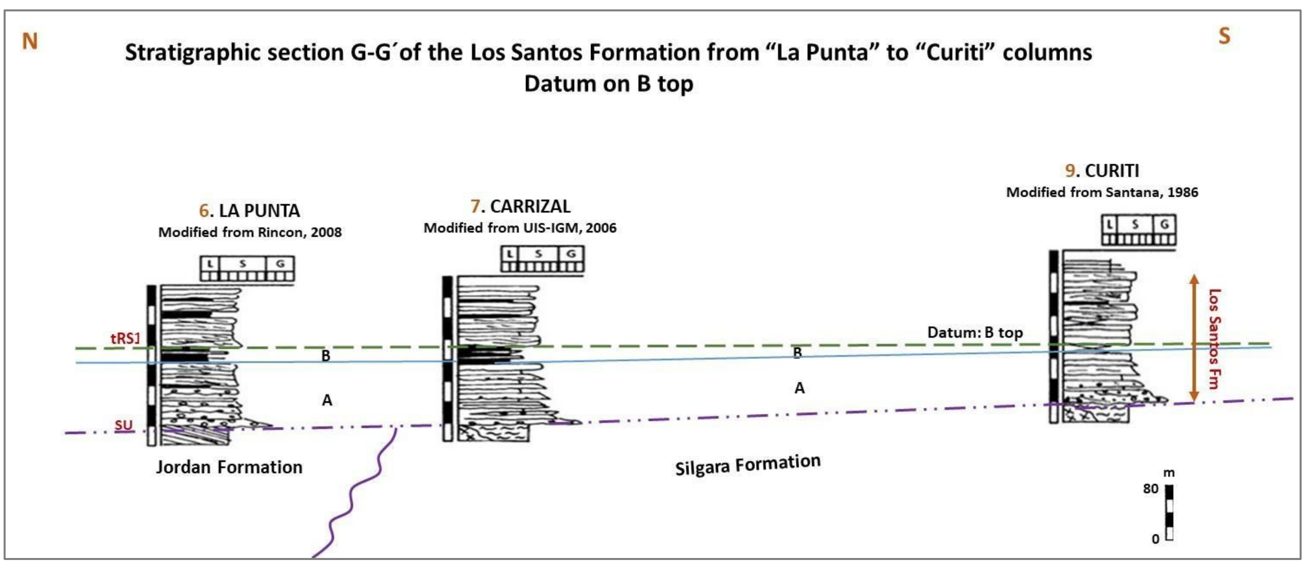

Figure 20. Stratigraphic section G-G´ from La Punta, Carrizal, and Curiti measured columns. Datum on B top.

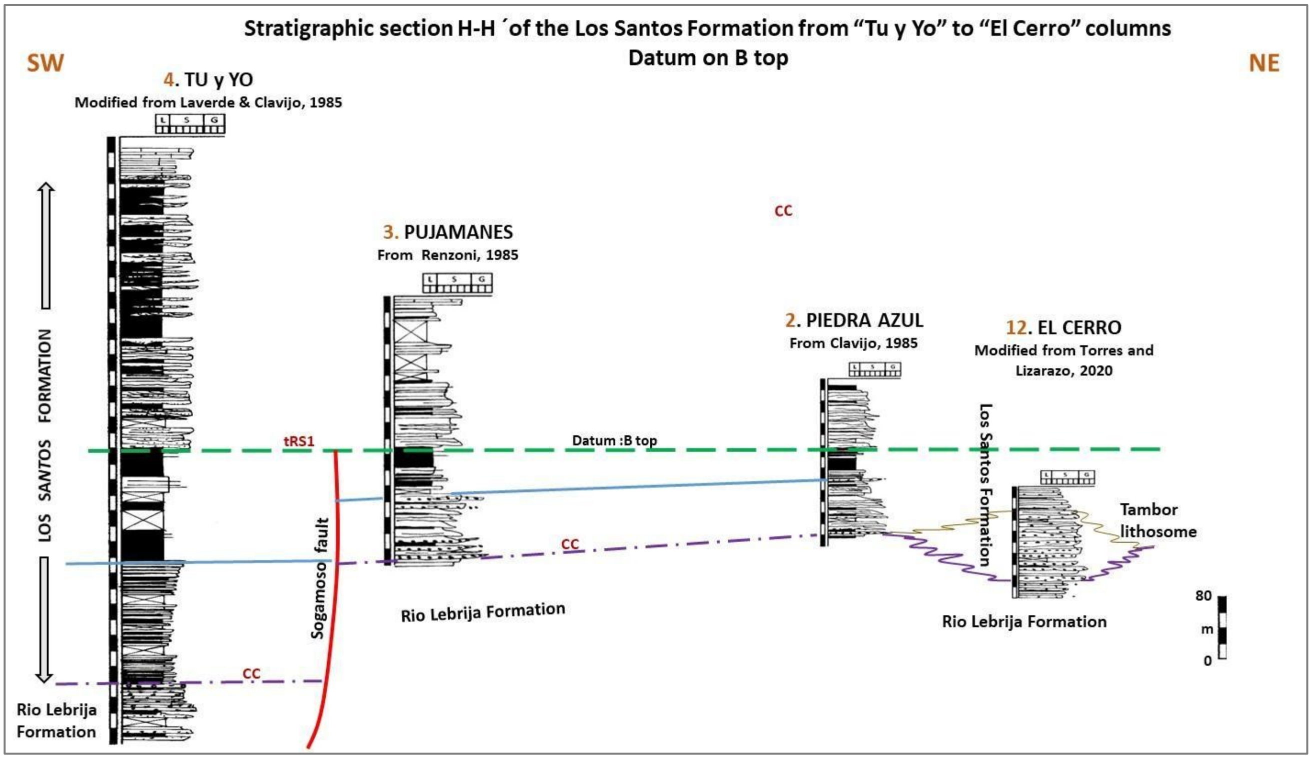

Figure 21. Stratigraphic section H-H´ from Tu y Yo, Pujamanes, Piedra Azul and El Cerro measured columns. Datum on B top.

5.1. Correlation Results

From the correlation of different stratigraphic sections (sections A-A 'to G-G') it is observed:

Stratigraphic section A-A´:
Sogamoso fault presents a normal sense of movement toward S with NW-SE fault trace (hanging-wall block).
A westward hanging wall sense of movement is presenting the Bucaramanga fault
General thickening of the Los Santos formation toward SW.

Stratigraphic section B-B´:
In addition to the normal faulting manifested by the Suarez fault, an important structure with the same sense of movement is the Zapatoca fault located westward.
Jordan fault is an interpretative structure at the southeastern part of the study area due to the growing strata developed of segments A and B between El Roto and Curiti stratigraphic sections.

Stratigraphic section C-C´:
Subaerial unconformity is present in the relationship between La Punta and Carrizal columns.

The Suarez fault is the structure that put in contact the Jordan and Lebrija formations when facing La Punta and Pujamanes columns.

Stratigraphic section D-D´:
The block faulting is also present in the same formation. For example, the Jordan Fm is faulted when considering El Calicho and La Punta columns. Again, the Suarez structure shows the faulted contact between the Jordan and Rio Lebrija formations observing the Platanalito and El Calicho stratigraphic columns.

Stratigraphic section E-E´:
Escalation of normal faulting to the west when observing the stratigraphic columns Carrizal, El Calicho, Ojo de Agua and Tu y Yo. Consequently, the Silgara, Jordan and Rio Lebrija formations are staggered like a playing card.

Stratigraphic section F-F´:
The Sogamoso fault appears to be a transtensive and oblique fault controlling the Los Santos Formation toward north (see Pujamanes stratigraphic column). Possibly, the Jordan fault is covered for the tidal ravinement surface (tRS1) interpreted at the base of segment C.

Stratigraphic section G-G´:
The Los Santos Formation, which is in discordant contact with the underlying Jordan Formation in the La Punta stratigraphic column, has a nonconformity relationship with the Silgara Formation in the La Punta-Carrizal trajectory, where it appears in an apparent transgressive relationship. On closer inspection, the relationship between the sections of La Punta, Carrizal and Curiti is unconformable, located exactly at the base of the Los Santos Formation, which uniformly beveled both the Jordan Formation sedimentites and the rocks belonging to the Silgara Formation.

Stratigraphic section H-H´:
The main objective of this stratigraphic section is to show the presence of the Tambor lithosome at the base of the Los Santos Formation according to the El Cerro stratigraphic column. The Sogamoso fault is an important structural element facing the Pujamanes and Tu y Yo columns.

To summarize some of the observations referred to above, the following stands out:

The Suarez fault is the major structural element that controlled the thickness of sedimentation during the entire deposit of the Los Santos Formation.

The Zapatoca fault behaves similarly to the Suarez fault, both in vergence and effects of growing strata toward west.

An important structural feature of NW-SE orientation is the Sogamoso fault, which acts as an apparent transtensional fault.

Other faults such as Jordan constitute the faulted edge of part of the prevailing normal fault system.

The development of growth structures is evident, and the uneven movement of some of them.

The Los Santos Formation represents, in its basal part, the record of an important episode of tectonic pulse at the end of the Jurassic times that unevenly sliced all the units located to the east of the Suarez fault.

The hanging block of the Suarez fault, where the sediments that constitutes the Rio Lebrija Formation were being deposited, did not apparently experience the uplifting action and general erosion on which the base of the Los Santos Formation was deposited later.

The base of segment C of the Los Santos Formation is the record of an important sedimentological event, which allows establishing the first transgressive event of quartz-sandy facies from coastal facies located to the west. This event generated the development of a marine erosion surface (tidal ravinement surface –tRS1) at the mouth of the fluvial system that was developing in the lower part of the Los Santos Formation.

The tectonic activity continued to develop along with the deposit of the sediments that would constitute the Los Santos Formation. For this reason, apart from the studies by Julivert and Tellez, (1963) where they determine the presence of pre-Cretaceous and post-Jurassic faults, this study determines the presence of other important faults, and the growth strata character in response to this extensional tectonism.

6. Depositional model

Based on the previous analysis the sedimentological model of the Los Santos Formation in the Mesas and Cuestas region, the lowermost part of segment A east of the Suarez fault and the complementary block extension of the Lebrija-Solferino faulted areas are interpreted as the geologic record of alluvial deposits. The uppermost part of the segment A in the block east of the Suarez seems to record braided and meandering deposits. The region located westward of the Suarez fault –south of the Sogamoso fault records meandering deposits in the segment A.

A flat dominated zone with presence of lithologies and sedimentary structures that permit a quieter environment, with some indications of tidal influence are interpreted as a central basin or estuary basin (segment B). The presence of an important scouring surface (tRS1) is cutting the top of segment B, over which there are deposits of a complex estuarine transgressive river mouth (segments C and D). A hypothesized scour surface named as tRS2 is placed inside the Cumbre Formation, below fossiliferous siltstones and sandstones and highly bioturbated dolomitic sandstones according to the model proposed by Allen and Posamentier (1993, 1994) for the Gironde estuary. A schematic model is presented in figure 22.

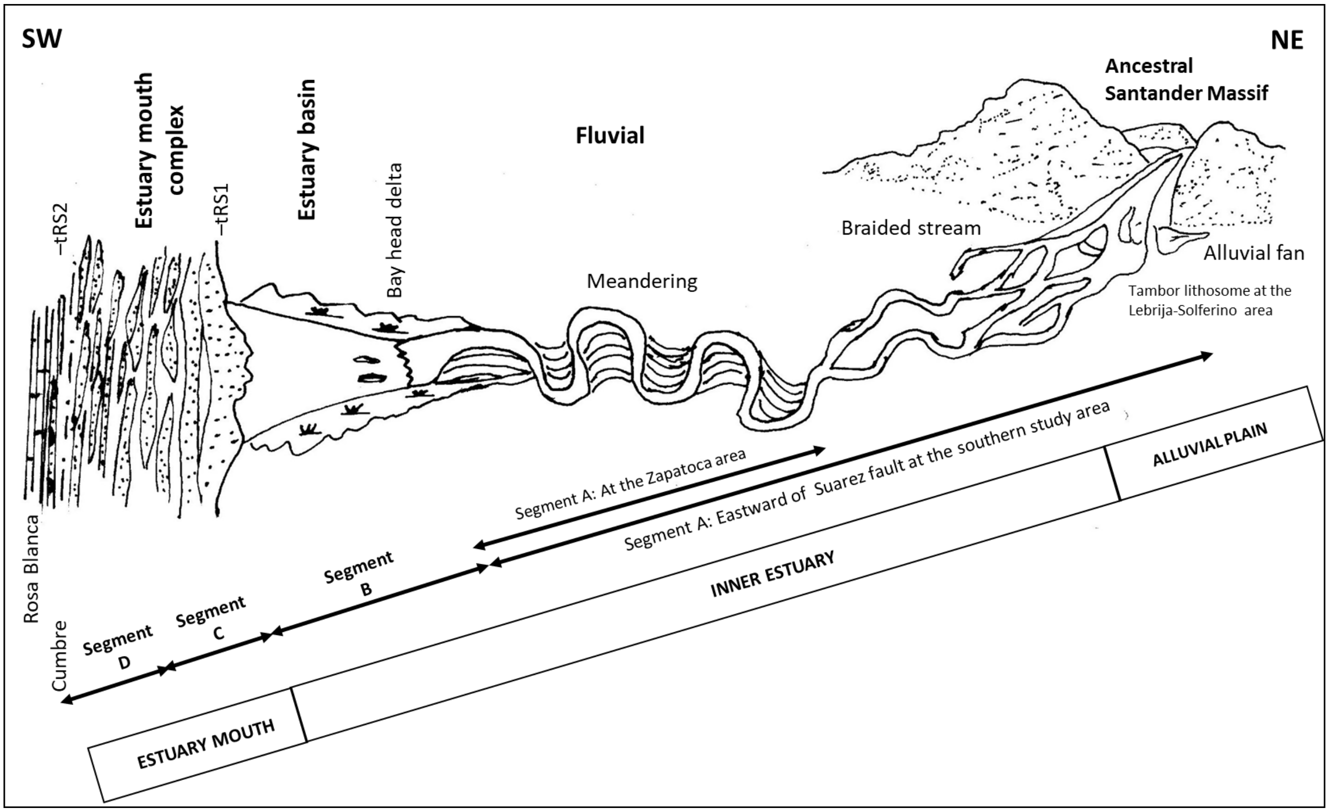

Figure 22. Schematic depositional model of the Los Santos Formation in the Mesas and Cuestas region. (tRS1: Tidal ravinement 1; tRS2: Tidal ravinement surface 2).

7. Conclusions

The facies variability of this succession is accompanied by several key stratigraphic surfaces indicating that a complex stage of events occurred during the Los Santos deposition. These events appear to be related to an initial episode of significant tectonism at the times of deposition of the base of the Los Santos Formation in a latest Jurassic time, that beveled the lands located east of the Suarez fault. From this initial episode, the subsequent deposition of the lower Los Santos Formation took place. A second episode (Upper Los Santos Formation or segments C and D of this study) is more related to base-level changes that conditioned the mixed wave and tide processes as a direct consequence of probably minor tectonic pulses that occurred during transgression. For this reason, during transgression, two major sources of sediments were available to fill the area of deposition: fluvial sediments from the hinterlands (ancestral Santander Massif), and sediments sourced from the shelf and shorelines located westward. Consequently, during transgression, the latest Jurassic-earliest Cretaceous fluvial valleys were initiated to be filled from both ends.

Westward of the Suarez, the segment A seems to reflect the development of a renewed fluvial system over an oldest one (Rio Lebrija Formation) generating between these two units at least an onlapping contact, which could be related as a paraconformity, but since there is no irrefutable evidence of the character of contact between the Rio Lebrija and Los Santos formations, or of a possible stratigraphic hiatus, it has been preferred to interpret this contact as a correlative conformity (CC) according to Haq (1991).

Eastward of the Suarez fault, the stratigraphic hiatus associated with the subaerial unconformity is variable, due to differential block faulting and fluvial incision. The regional block tilting to the west was the main responsible for the gradual subaerial erosion expansion during the stage of base-level fall.

The segment B, is interpreted as a central estuary deposit due to the lithology and sedimentary structures.

The segment C seems to represent high-current velocities, where migration of large-scale bedforms (i.e., two-dimensional and three-dimensional dunes) is the dominant process (Boyd et al., 2006; Dalrymple *et al*., 1994, Dalrymple, 2010). On high-energy sandbodies, rapidly migrating bedforms generally preclude intense bioturbation.

In transgressive river-mouth settings like the Los Santos Formation, a transgressive ravinement surface (bottom of the segment C) is preserved as distinct scoured contact (tRS1). This ravinement surface separates the dominantly sandy deposits of the estuary-mouth complex (segment C) of those of finer sediments (segment B) that constitute the central basin.

In the case of the Los Santos, after the deposition of Segment C various small episodes of forced regressions and subsequent transgressive periods are recorded in the succession of segment D. Interpreted forced regressions episodes in Segment D require fluvial systems to adjust to new settings, where fluvial processes are primarily controlled by depositional base-level changes.

Acknowledgements

I appreciate the invitation of Jairo Clavijo, Georgina Guzman and Angela Torres to join the survey of this unit in the Platanalito area, where we had the opportunity to discuss new concepts. The results of the Platanalito section are in progress and will be presented soon too. The conclusions expressed in this revisit exercise of the Los Santos Formation were the maturation of some ideas initially conceived during the work carried out in the type section of the El Roto trail in 1985, but now with the opportunity to return to the outcrops after some experiences in other basins. The development of these ideas was the necessary input to visit other places of interest on my own. A thorough review of the initial manuscript by the editor and the journal's guest reviewers is especially appreciated.

References

Aldana, S. C., (2008). Estratigrafía de la Formación Los Santos en las secciones de La Navarra y El Calicho en la Mesa de Los Santos (Departamento de Santander). Trabajo de grado presentado para optar al título de Geóloga. Universidad Industrial de Santander, Facultad de Ingenierías Fisicoquímicas, Escuela de Geología. Bucaramanga. 29 p.

Allen, G.P., (1991). Sedimentary processes and facies in the Gironde estuary: a Recent model for macrotidal estuarine systems, in Smith, D.G., Reinson, G.E., Zaitlin, B.A., and Rahmani, R.A., *eds.*, Clastic Tidal Sedimentology: Calgary, Canadian Society of Petroleum Geologists Memoir 16, p 29-40.

Allen, G., and Posamentier, H.W., (1993). Sequence stratigraphy and facies model of an incised valley fill: The Gironde estuary, France. Journal of Sedimentary Petrology, Vol. 63, No. 3, May, p. 378-391.

Allen, G.P., and Posamentier, H.W., (1994). Transgressive facies and sequence arquitecture in mixed tide and wave-dominated incised valleys: example from the Gironde estuary, France. Incised-valley Systems: Origin and Sedimentary Sequences, *SEPM Special Publication* No. 51: 225-240.

Bates, R. L., and Jackson, J. A. (*Eds*.), (1987). Glossary of Geology – Third edition. American Geological Institute, Alexandria, Virginia, p. 788.

Boyd, R., Dalrymple, R.W., Zaitlin, B.A., (2006). Estuarine and incised-valley facies models. *In*: Posamentier, H.W., Walker, R. (*Eds*.), Facies Models Revisited. *SEPM Spec. Publ*., vol. 84, p. 175–240.

Brueckner, W.D., (1954). Note on some fossils from the Girón group in the Río Lebrija valley, department of Santander, Colombia: Journal of Paleontology, v. 28, p. 112–113

Catuneanu, O., (2006). Principles of Sequence Stratigraphy. Elsevier, Amsterdam, 375pp.

Cediel, F., (1968). El Grupo Girón, una molasa mesozoica de la Bogotá. XVI (1-3): 5-96. Cordillera Oriental. Boletín Geológico Servicio Geológico Nacional

Clavijo, J., (1985). La secuencia facial de la Formación Los Santos por la quebrada Piedra Azul: registro de una hoya fluvial evanescente. In: Etayo-Serna, F. Laverde, F. (*eds*) *Proyecto Cretácico, Contribuciones. Publicaciones Geológicas Especiales del Ingeominas*, Bogotá 16, IV (1-17).

Cooper, M.A., Addison, F.T., Álvarez, R., Coral, M., Graham, R.H., Hayward, A.B., Howe, S., Martinez, J., Naar, J., Peñas, R., Pulham, A.J., and Taborda, A., (1995). Basin development and tectonic history of the Llanos basin, Eastern Cordillera, and Middle Magdalena Valley, Colombia: American Association of Petroleum Geologists Bulletin, v. 79, p. 1421–1443.

Dalrymple, R.W., Boyd, R., Zaitlin, B.A., *eds*., (1994). Incised-valley systems: origin and sedimentary sequences. *Society of Economic Paleontologists and Mineralogists. Special Publication* 51, 391 p.

Dalrymple, R.W. and Choi, K. (2007). Morphologic and facies trends through the fluvial–marine transition in tide-dominated depositional systems: a schematic framework for environmental and sequence stratigraphic interpretation. *Earth-Sci. Rev*., 81, 135–174.

Dalrymple, R.W., (2010). Tidal depositional systems. In: James, N., Dalrymple, R. (*Eds*.), Facies Models 4. *Geol. Ass. Can*., *St. John's*, Geotext 6, pp. 201–231.

Desjardins, P.R., Buatois, L.A., Pratt, B.R., Mangano, M.G., (2011). Sedimentological–ichnological model for tide-dominated shelf sandbodies: lower Cambrian Gog

Group of western Canada. *Sedimentology* 59, 1452–1477.

Etayo-Serna, F., and Rodriguez, G., (1985). Edad de la Formación Los Santos, *in* Etayo-Serna, F., and Laverde, F., eds., Proyecto Cretácico: Contribuciones: INGEOMINAS Publicaciones Geológicas Especiales 16, no. XXVI, 13 p.

Etayo-Serna, F., (1989). Análisis facial del inicio del avance marino del Cretácico en la región SW del Macizo de Santander, *in* Guía de excursión técnica, V Congreso Colombiano de Geología, marzo 13–14, Bucaramanga-Colombia, p. 7

Etayo-Serna, F. (2019). Estudios geológicos y paleontológicos sobre el Cretácico en la región del embalse del rio Sogamoso, Valle Medio del Magdalena. In: Compilación de los estudios geológicos oficiales en Colombia-Volumen XXIII. Con la dirección científica y edición de Fernando Etayo-Serna y la participación de Etayo-Serna, F., Montoya-Arenas, D.M., Moreno-Sánchez, G., Terraza-Melo, R., y Guzman-Ospitia, G. Servicio Geologico Colombiano, Bogotá, noviembre 2019. ISBN digital: 978-958-52317-8-8.

Etayo-Serna, F., and Guzman-Ospitia, G., (2019). Formacion Rosa Blanca: subdivisión de la Formación y propuesta de Neoestratotipo. Sección laguna El Sapo, vereda El Carrizal, municipio de Zapatoca, departamento de Santander. In: Compilación de los estudios geológicos oficiales en Colombia-Volumen XXIII. Servicio Geológico Colombiano, Bogotá. p 3-54.

Haq, B. U. (1991). Sequence stratigraphy, sea-level change, and significance for the deep sea. *In* Sedimentation, Tectonics and Eustasy (D. I. M. Macdonald, *Ed*.), pp. 3–39. International Association of Sedimentologists Special Publication 12.

Horton, B.K., Anderson, V.J., Caballero, V., Saylor, J.E., Nie, J., Parra, M., and Mora, A., (2015). Application of detrital Zircon U-Pb geochronology to surface and subsurface correlations of provenance, paleodrainage, and tectonics of the Middle Magdalena Valley of Colombia: Geosphere, v. 11 p. 1790-1811, https://doi.org/10.1130/GES1251.1

Jiménez, G., García-Delgado, H., and Geissman, J.W., (2021). Magnetostratigraphy and magnetic properties of the Jurassic to Lower Cretaceous Girón Group (northern Andes, Colombia): Geosphere, v. 17, no. X, p. 1–25, https://doi.org/10.1130 /GES02186.1

Julivert, M., (1963). Nuevos datos sobre la dinámica del ámbito del Macizo de Santander durante el Secundario (Cordillera Oriental, Colombia). Boletín de Geología, Revistas UIS 12, p. 45-49.

Julivert, M., Tellez, N. (1963). Sobre la presencia de fallas de edad pre-Cretácica y post-Girón (Jura-Triásico) en el flanco W del Macizo de Santander (Cordillera Oriental de Colombia). Boletín de Geología, Revistas UIS 12, p.5-17.

Julivert, M., Barrero, D., and Navas, J., (1964). Geología de la Mesa de Los Santos. Boletín de Geología, Revistas UIS, no 18, p. 5-11. Bucaramanga.

Langenheim, R. L., (1959). Preliminary report on the stratigraphy of the Groin Formation in Santander and Boyacá. Boletín de Geología, Univ. Ind. Santander., n.3, p. 35-40, 4 fs., Bucaramanga.

Langenheim, J.H., (1961). Late Paleozoic and Early Mesozoic plants fossils from the Cordillera Oriental of Colombia and correlation of the Girón Formation: Boletín Geológico, v. 8, no. 1–3, p. 95–132.

Laverde Montaño, F., (1985). La Formación Los Santos: un depósito continental anterior al ingreso marino del Cretácico. In: Etayo-Serna, F., & Laverde, F., (*eds*) Proyecto Cretácico, Contribuciones. *Publicaciones Geológicas Especiales del Ingeominas*, Bogotá 16, XX (1-24).

Laverde, F., and Clavijo, J., (1985). La Formación Los Santos: Análisis facial de la Formación Los Santos, según e corte ``Tu y Yo” (Zapatoca), in Etayo-Serna, F., and Laverde, F., eds., Proyecto Cretácico: Contribuciones: INGEOMINAS Publicaciones Geológicas Especiales 16, no. VI, 13 p.

Moreno-Sánchez, G., (2019). Mapa geológico del Valle Medio del Magdalena en los alrededores del puente El Tablazo, departamento de Santander. Estudios geológicos y paleontológicos sobre el Cretácico en la región del embalse del río Sogamoso, Valle Medio del Magdalena. Compilación de Estudios Geológicos Oficiales en Colombia, vol XXIII, Bogotá. Servicio Geológico Colombiano.

Nemec, W., and Steel, R.J., (1984). Alluvial and coastal conglomerates: their significant features and some comments on gravelly mass-flow deposits. *In*: Koster, E. H. and Steel, R. J. (*Eds*.), Sedimentology of Gravels and Conglomerates. Canadian Society of Petroleum Geologists, Memoir 10 (1984). p. 1-31.

Ogg, J.G., Ogg, G.M., and Gradstein, F.M., 2016, A Concise Geologic Time Scale: 2016: Amsterdam, Elsevier, 240 p.

Olariu, C., Steel, R.J., Dalrymple, R.W., and Gingras, M.K., (2012). Tidal dunes versus tidal bars: The sedimentological and architectural characteristics of compound dunes in a tidal seaway, the lower Baronia Sandstone (Lower Eocene), Ager basin, Spain. Sedimentary Geology 279, p.134-155.

Osorio-Afanador, D., (2016). Estratigrafía y deformación del Grupo Girón en el anticlinorio de los Yariguíes (Anticlinal de los Cobardes) Sectores Zapatoca y Río Lebrija. [proyecto de grado Geología]: Bucaramanga, Universidad Industrial de Santander, Facultad de Ingenierías Fisico-químicas, 173 p.

Pons, D., (1982). Études paléobotanique et palynologique de la Formation Girón (Jurassic moyen– Crétacé inférieur) dans la région de Lebrija, département de Santander, Colombie: 107 Congress National des Sociétés Savants, Brest, Sciences, no. 1, p. 53–78

Porada, H., and Bouougri, E. H. (2007). Wrinkle structures – a critical review. *Earth Sci. Rev.* 81, 199–215. doi: 10.1016/j.earscirev.2006.12.001

Porada, H., Ghergut, J., and Bouougri, E. H. (2008). Kinneyia-type wrinkle structures – critical review and model of formation. *Palaios* 23, 65–77. doi:10.2110/palo.2006. p06-095r.

Renzoni, G., (1985). Paleoambientes de la Formación Tambor en la quebrada Pujamanes. *In* Proyecto Cretácico, Contribuciones by Etayo-Serna, F., and Laverde Montaño, F. (*eds*). Publicaciones Geológicas Especiales del Ingeominas, no. 16. Bogotá.

Rincón, M.A, (2008). Estratigrafía de la Formación Los Santos en las secciones estratigráficas La Punta, Carrizal (Mesa de Los Santos) y La Cuevana (Curiti), departamento de Santander. Proyecto de investigación: Investigación geológica e hidrogeológica en la Mesa de Los Santos, sector nordeste de Curití y borde occidental del Macizo de Santander, departamento de Santander. 45 p.

Roy, P.S., Thom, B.G., and Wright, L.D. (1980). Holocene sequences on an embayed high energy coast: an evolutionary model: Sedimentary Geology, v.26, p.1-19.

Rust, B.R., (1972). Structure and process in a braided river. Sedimentology, vol 18, p. 221-245.

Santana, J., (1986). Estratigrafía, facies y ambiente de depósito de la Formación Tambor en las localidades de Curití, Charta y Matanza (Santander). Trabajo de grado para optar al título de Geólogo. Universidad Nacional de Colombia, Facultad de Ciencias, Bogotá. 140 p.

Smith, N.D., (1974). Sedimentology and bar formation in the Upper Kicking Horse River, a braided outwash stream. Journal of Geology, vol. 82, p. 205-224.

Torres, J.M., and Lizarazo, J.A., (2020). Caracterización Estratigráfica y Sedimentológica del Conglomerado Rojo (Miembro Tambor) de La Formación Rio Lebrija (Grupo Girón). Trabajo de Grado para optar al título de Geólogo. Universidad Industrial de Santander, Facultad de Ingenierías Fisicoquímicas, Escuela de Geología, Bucaramanga. 112p.

Universidad Industrial de Santander (UIS) e Instituto Colombiano de Geología y Minería (Ingeominas), (2006). Proyecto de investigación geológica e hidrogeológica en la Mesa de Los Santos, sector noreste de Curití y borde occidental del Macizo de Santander, Departamento de Santander. Memoria explicativa. Acuerdo específico número 017 de 2007 complementario al convenio marco de cooperación No 005. Bucaramanga, diciembre de 2007, 117 p.

Velandia, F., (2017). Cinemática de las fallas mayores del Macizo de Santander - énfasis en el modelo estructural y temporalidad al sur de la Falla de Bucaramanga [Ph.D. thesis]: Bogotá, Universidad Nacional de Colombia–Sede Bogotá, 222 p

Ward, D. E., Goldsmith, R., Jimeno, A., Cruz, J., Restrepo, H., y Gómez, E. (1973). Cuadrángulo H-12, Bucaramanga. Planchas 109, Rionegro, y 120, Bucaramanga. Cuadrángulo H-13, Pamplona. Planchas 110, Pamplona, y 121, Cerrito. Escala 1:100.000. Boletín Geológico, 21(1-3) p. 1–132.

Zamarreño de Julivert, I., (1963). Estudio petrográfico de las calizas de la Formación Rosablanca en la región de la Mesa de Los Santos (Cordillera Oriental, Colombia). Boletín de Geología–Universidad Industrial de Santander, No 15, pp 5-34, 4 figs., 4 ls., Bucaramanga, Colombia.

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