TECTONOSTRATIGRAPHY OF THE CRETACEOUS SILICICLASTIC RESERVOIRS IN THE PUTUMAYO AND NORTHERN ORIENTE BASINS (COLOMBIA-ECUADOR)

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RESUMEN

Las Cuencas de Putumayo y Oriente (POFB) constituyen los segmentos norte y central de la Megacuenca de Marañon–Oriente–Putumayo (MOP), la tercera región petrolífera de mayor potencial exploratorio de Latinoamérica (excluyendo Venezuela). La secuencia Cretácica en la POFB hace onlap contra el basamento hacia el Este. Hacia el Oeste, la secuencia fue levantada y exhumada. La secuencia Cretácica incluye depósitos siliciclásticos y calcáreos de hasta 1000 ft, acumulados en diferentes ambientes. Sin embargo, las unidades reservorio con la mayor producción corresponden a los intervalos siliciclásticos de los sistemas fluviales a marino marginales. A pesar de los numerosos estudios, estos han sido usualmente enfocados independientemente, ya sea en la cuenca de Oriente o Putumayo y sin integración. Este artículo, en cambio, ofrece una visión integrada de la POFB. Se definió un marco tectonoestratigráfico y paleoambiental basado en análisis previos y nuevas interpretaciones sobre sísmica 2D/3D, registros de pozo, cuttings y núcleos. Así se construyó una correlación actualizada, mapas de espesor y facies. Los mapas de espesor, integrados con los sistemas de fallas regionales, incluyen la relación Net/Gross con el objetivo de diferenciar el espesor, niveles de energía y procesos sedimentarios asociados. El análisis de volumen de arcilla fue realizado usando los registros de GR y SP. Esta aproximación no solo proporciona una nueva visión de la paleogeografía del Cretácico sino también sugiere las áreas con la mayor probabilidad de tener mejores características de reservorio. Este análisis puede ser considerado como una herramienta preliminar para proponer áreas potencialmente prospectivas para ser evaluadas más detalladamente.

INTRODUCTION

The present study constitutes an integrated approach to the stratigraphy and structural configuration of the main Cretaceous reservoirs along the Putumayo Basin and the northern end of the Oriente Basin.

The sub-Andean foreland basin group developed in the western and northern South America is one of the most famous foreland basin groups in the world and is also an important hydrocarbon province. The sub-Andean Putumayo-Oriente-Marañón basin, extending across Colombia, Perú and Ecuador has been explored for almost a century, and although mature, the Colombian portion (Putumayo) remains largely unexplored. The traditional focus of exploration in the basin has been Cretaceous clastic reservoirs on subtle, structural traps.

Exploration in the Oriente Basin was initiated in 1921, although it was not until 1937 that Shell Exploration drilled the first well. The first listed field discovery is Orito, (Texaco-1963), in the Putumayo Basin.

The main oil and gas reservoirs for the Putumayo Basin in Colombia are in the Cretaceous Caballos and Villeta Formations and the Tertiary Pepino Formation. Ecuador's Oriente Basin production is mostly from sandstones of the Cretaceous Hollín and Napo Formations, and Peru's Marañón Basin reservoirs are sandstones of the Cretaceous Cushabatay, Agua Caliente, Chonta, and Vivian Formations.

STUDY AREA AND REGIONAL GEOLOGY

The study area is located in the Putumayo Basin in Colombia and the northern portion of the Oriente Basin in Ecuador, which together with the Marañón Basin in Peru constitute the Marañón-Oriente-Putumayo mega-basin (MOP) (Figure 1). This basin complex is part of the sub-Andean basin system that occurs throughout South America, east of the Andes Range.

This province is an asymmetric foreland basin that covers about 320,000 km^2 (Mathalone and Montoya, 1995), extends along and lie parallel to the Andes. The subsidence axis of the basin is located in front of the Putumayo Foreland.

The Putumayo Foreland Basin (PFB) is bounded to the west by the Colombian Andes, a Cenozoic fold-thrust belt of mainly Mesozoic sedimentary rocks. The Guyana shield represents the eastern and northern borders of the PFB and consists of the Caquetá basement arch, a

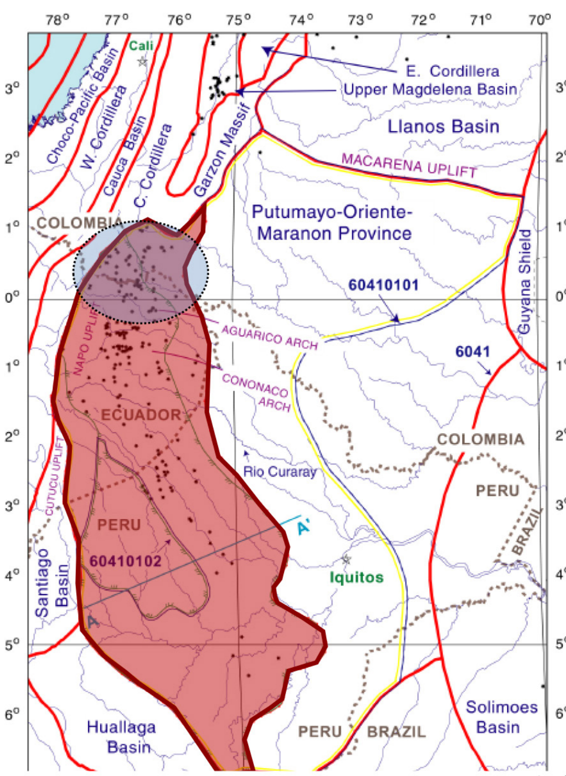

Figure 1. Marañón-Oriente-Putumayo(MOP) province. Scale 1:7,100,000. (USGS, 2001).

topographic mountain range which separates the PFB from the Caguán-Yarí sedimentary basin. Finally, the Vaupes subsurface arch separates the PFB from the Llanos basin to the north (Figure 2). To the south, the PFB is continuous with the Marañon foreland basin of Ecuador and the Oriente basin of Peru. Together, these cratonic basement, and pre-foreland structural features delineate the triangular-shape of the PFB.

The basin presents a geological evolution controlled by various tectonic events that have transformed it from a rift-type basin in the Triassic-Jurassic, passing through a retro-arc basin in the Cretaceous, to a foreland-type basin from the Late Maastrichtian, ending with the action of the Andean Orogeny in the Late Miocene, which produced reactivation of existing faults and the generation of the Andean Piedemonte system (Fechi *et al.*, 2022, this volume).

Three main deformation zones can be defined: 1) Contractional Zone, characterized by large shortenings that lift the sedimentary sequence, 2) Transition Zone and 3) Reactivation Zone in

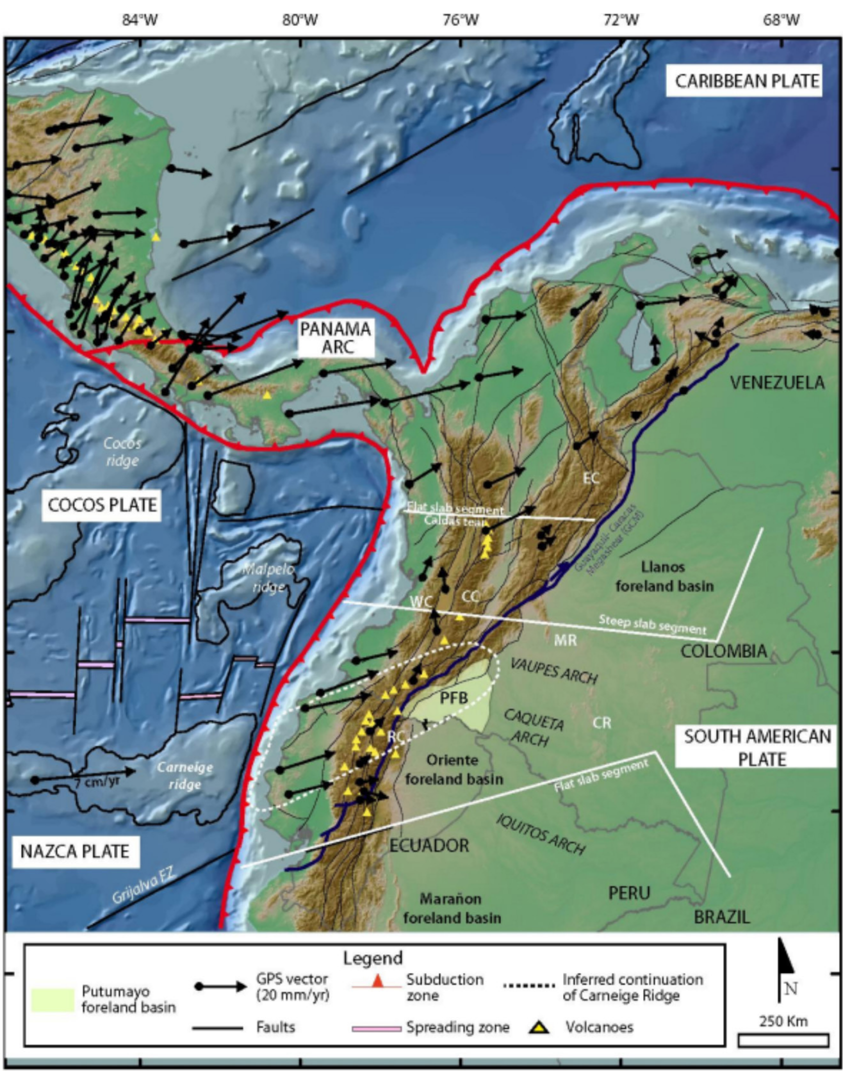

Figure 2. Regional tectonic setting (Pachon, 2013).

the foreland, where the old normal faults are exploited by the Andean Orogeny to transmit stress, generating reactivation structures and in some cases, dextral transpression (Fechi et. al., 2022, this volume).

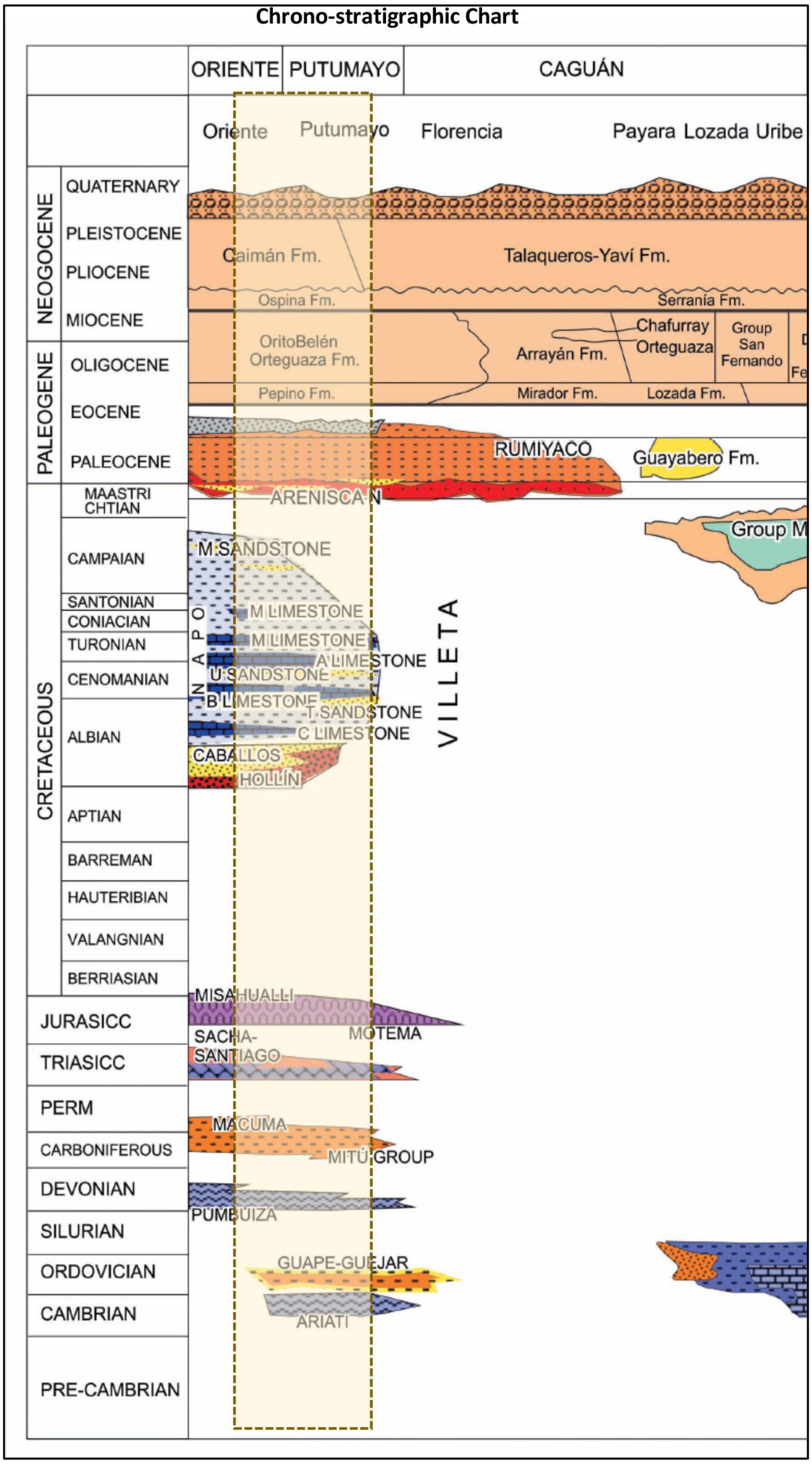

Figure 3. Comparative Chrono-stratigraphic Chart for Oriente, Putumayo and Caguán Basin (ANH, 2011).

In the Putumayo Basin (the same as in the Oriente Basin in Ecuador), the sedimentary sequence comprises units from the Paleozoic to Recent (Figure 3, Kairuz *et al.*, 2000). The basin is divided into three mega-sequences: Pre-Aptian, Cretaceous and Cenozoic, with different sedimentological characteristics in each subbasin which reflect the different stages of tectonic development.

The Pre-Aptian Megasequence is composed of sediments underlain by igneous and metamorphic rocks; they fill a Pre-Cambrian block system of graben and horst type, which exists both in the Putumayo and the Oriente basins. Faults are north south and form production trends (Figure 4). In these basins the oldest rocks are identified in outcrops in the Garzon Massif, with Proterozoic ages (Rodríguez *et al.*, 2003).

The Cretaceous Megasequence comprises 5 main sequences, with ages that span from Aptian to Maastrichtian (Caballos and Villeta Formations). The environments of deposition for these sequences were controlled by abrupt changes in accommodation space, marked by the presence of rapid progradation (mixed platforms to fluvial-estuarine systems) associated to forced regressions. Rapid progradation pulses deposited the main reservoir units in the basin and are heavily influenced by the first episodes of uplift within the Central Cordillera (western Putumayo Basin limit). These sequences begin with basal sandy bodies, overlain by limestones or shales, which indicate deepening processes and may be compared with sequences identified in the Oriente and Upper Magdalena Valley basins (Mora *et al.* 2010, Figure 5).

The Cenozoic Megasequence represents a continental foreland fill and was controlled by the onset of orogenic processes and associated uplift pulses which influenced the Caguan-Putumayo foreland area. At least two main uplift episodes were identified within the Cenozoic: during the

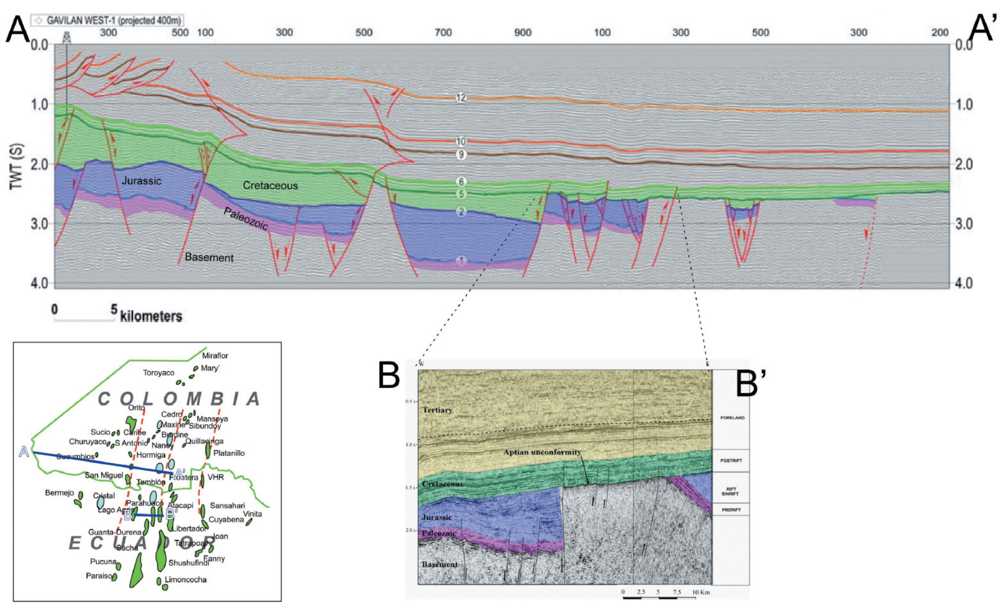

Figure 4. Structural Configuration to the Basement. The seismic image shows a system of blocks in horst and grabens sequence (ANH, 2011).

Eocene and Miocene, as a result of the mountain building processes of the Cordillera Central and Oriental. Four main sequences were established, which resulted in the deposition of the Rumiyaco Fm., Pepino Fm., and Orteguaza Fm. These units involve important reservoir intervals.

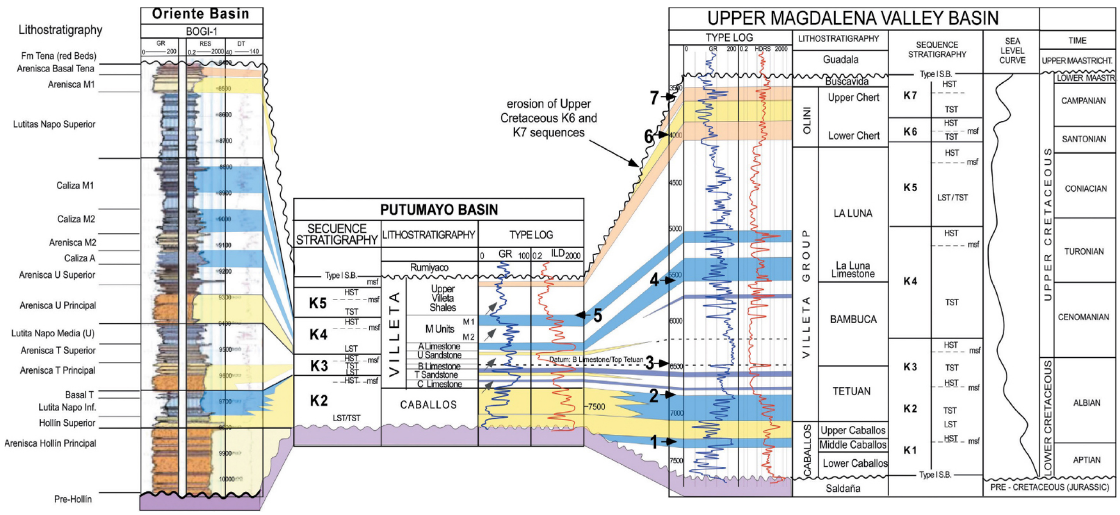

Figure 5. Stratigraphic Cycles comparison identified in the Oriente, Putumayo and Lower Magdalena Valley Basin. Modified from Mora, Mantilla and De Freitas 2009 (ANH, 2011).

Structural Setting

The Garzon Massif and the Florencia paleohigh are two structural elements present along the entire development of this basin (Figure 6); the location of the latter is mainly evidenced by interpretation of the Bouguer anomaly map, as no surface evidence exists.

The Florencia paleohigh divides the Caguán and Putumayo sub-basins, marking the different depositional environments on each side.

Another structural element within the basin is the Garzón Massif, which is located to the W of the basin and shows outcrops corresponding to the uplift process of the Central Cordillera.

The structural style within the Putumayo Foreland Basin is characterized by high-angle thick-skinned reverse faulting, which is commonly associated to inversion of Jurassic–Triassic normal faults. Positive inversion of Triassic-Jurassic half-grabens occurred during different tectonic episodes, including Early Cretaceous, Late Cretaceous, Eocene, and Pliocene-Pleistocene (Baby 2013). This thick-skinned fault system affects primarily the pre-Cenozoic sequence with just some minor reactivation occasionally affecting the Cenozoic deposits.

Toward the south, the basin can be subdivided into three main structural domains: the Sub-Andean domain is the most deformed area in the basin, corresponds to the wedge-top depozone and is affected mainly by NE–SW thick-skinned east-verging faults; the Proximal Foredeep domain is the deepest area of the Putumayo basin influenced by NNE–SSW trending thick-skinned faults, with low vertical displacement and several kilometers of length; and the External Foredeep domain is the least deformed zone, affected by high-angle reverse-inverted faults, with subtle vertical displacement and a preferential vergence toward the west. The faults in the three domains have been the product of pre-Cretaceous rift systems, reactivated during tectonic episodes in the Early Cretaceous, Late Cretaceous, Paleogene, and Pliocene–Pleistocene.

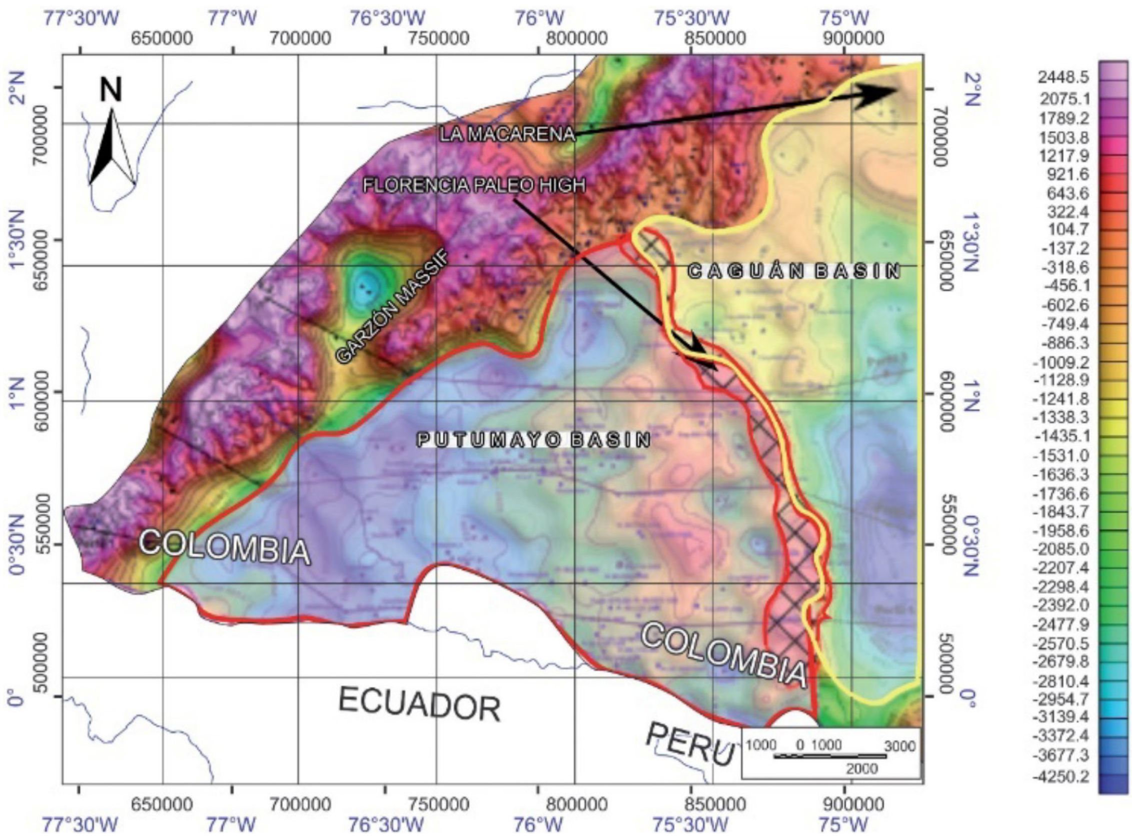

Figure 6. Interpreted Depth Structural Map at top of Paleozoic, from Bouguer Anomalies Maps (ANH, 2009).

METHODOLOGY

Sedimentological Analysis

The sedimentological analysis was carried out on 300 ft of the Platanillo-21 well, Putumayo basin (Figure 19). The core samples were described to identify the lithology, sedimentary structures and facies present in the cretaceous siliciclastic intervals, this data represents a valuable input to understand the depositional environment and to characterize those reservoirs.

T Sandstone

This interval is composed by fine to medium grain - occasionally coarse grain - sandstones with scarce siltstone layers. Reactivation surfaces, mud drapes and calcite nodules were observed in the core (Figure 7). Glauconitic sandstones and coal layers occur only at the top of this interval. The presence of mud drapes, low angle-cross stratification, calcite nodules, reactivation surfaces and glauconitic sandstones suggest a transitional environment for the deposition of those sediments, probably in an estuarine tidal dominated setting. There is also low evidence of bioturbation.

U Sandstone

This interval is comprised by two members: Lower U Sandstone and Upper U Sandstone. The Lower U Sandstone is a fining upward succession composed of medium to fine grain sandstones with low angle-cross stratification, lenticular bedding occurs towards the top where shale layers are thin and continuous. Scarce rip-up clasts of variables sizes were observed. This member is capped by a thin shale layer underlain by medium bioturbated fine grain sandstones. The Upper U Sandstone consists of limestone layers with fossil fragments which are interbedded with shale layers with pyrite nodules, those were deposited at the base of this member. Fine to medium grain sandstones with low angle-cross stratification were deposited overlying the basal limestone-shale layers. Mud drapes and mud clasts were observed in the sandstone layers. Bioturbation is intense at the very top of this succession (Figure 8).

According to the core observations, it is possible to suggest that both U Sandstone members were deposited in a transitional environment, as well as the T Sandstone. However, the Upper U Sandstone shows more evidence of an estuarine depositional setting whereas the Lower U Sandstone appears to have a higher fluvial influence.

M2 Sandstone

The M2 sandstone interval corresponds to a fine to medium grain sandstone intercalated, mainly in the basal section, with some shale layers with calcite nodules. Scarce mud drapes and a faint low angle-cross stratification was observed at the basal section whereas the medium and upper sections are massive with no clear structures evidencing an intense bioturbation (Figure 10). Glauconite content is variable, ranging from medium to high, suggesting a deeper deposition environment compared to the underlying U and T sandstones.

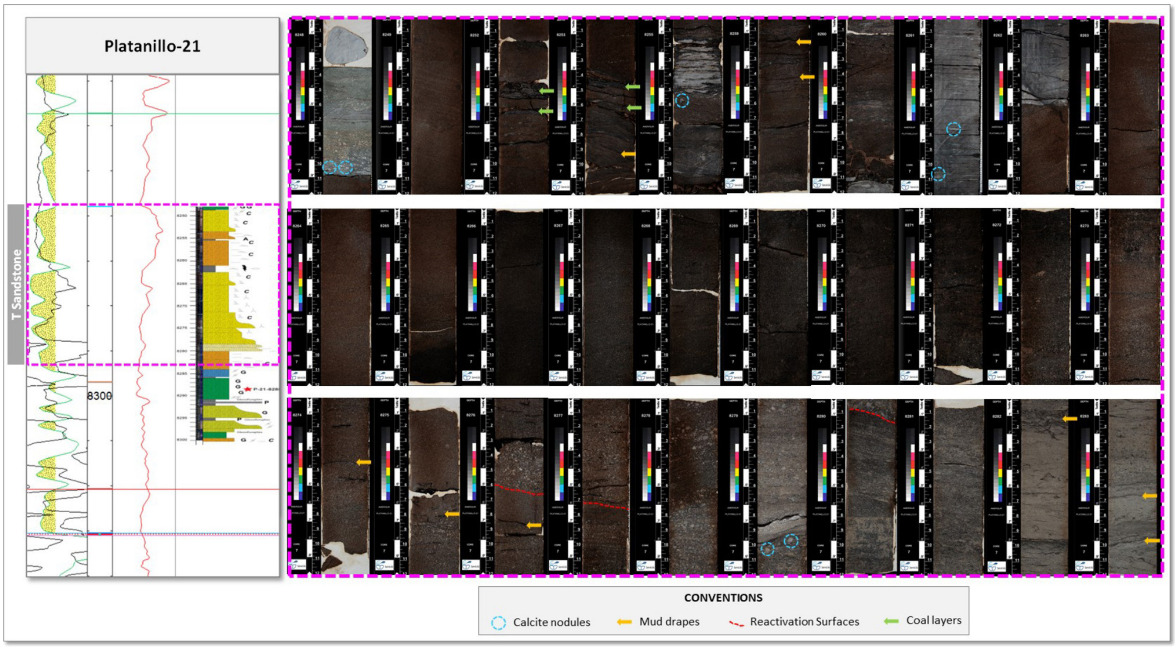

Figure 7. Core characteristics of the T Sandstone interval.

Figure 8. Core characteristics of the Lower U Sandstone interval.

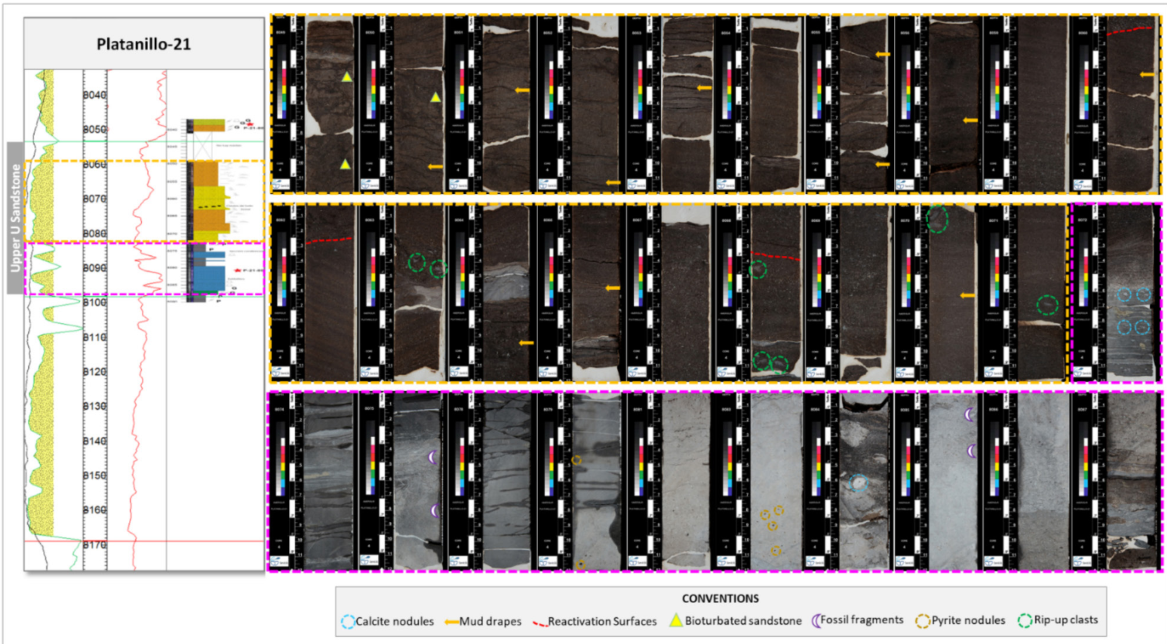

Figure 9. Core characteristics of the Upper U Sandstone interval.

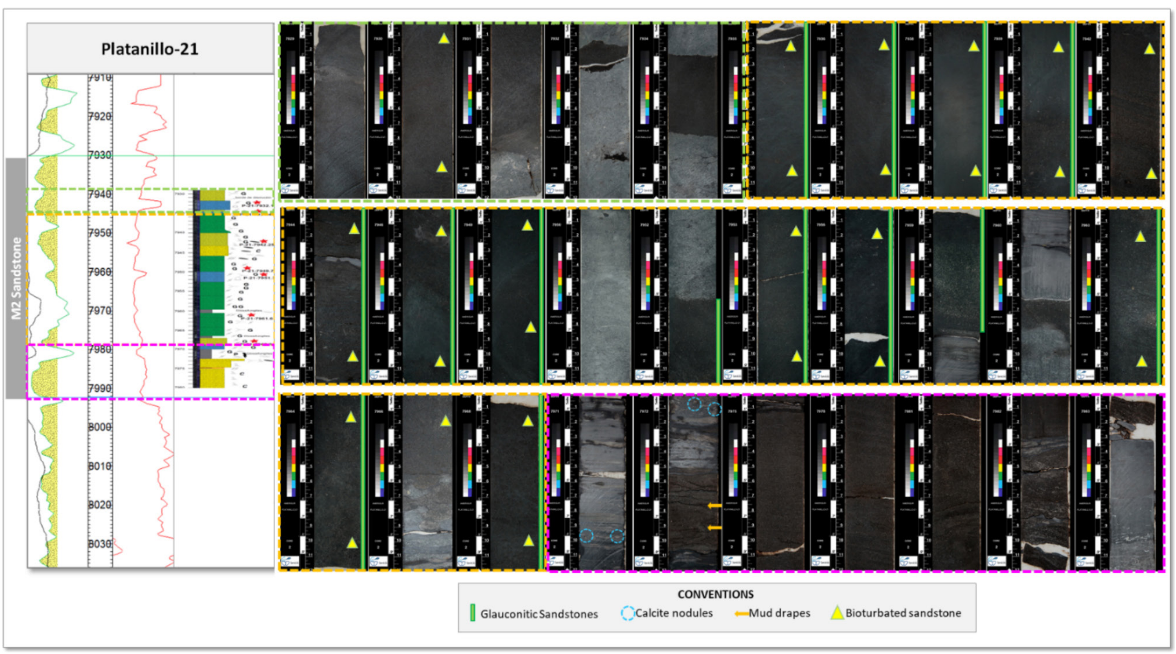

Figure 10. Core characteristics of the M2 Sandstone Interval.

Sequence Stratigraphic Framework

A sequence stratigraphic framework was proposed for the Cretaceous Megasequence in the Putumayo basin using as an analog the current subdivision published by Barragán *et al*, 2004, for the Oriente basin (Figure 11).

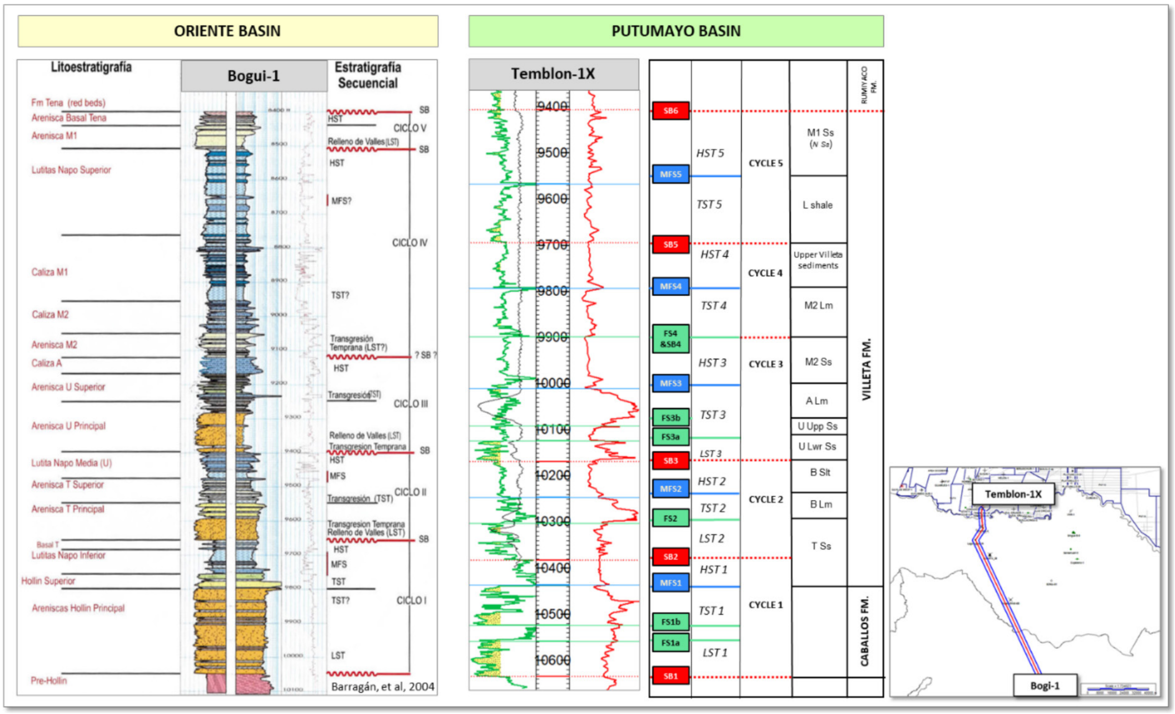

Figure 11. Sequence stratigraphic framework proposed for the Cretaceous interval in the norther part (Putumayo) of the MOP basin.

Stratal surfaces and major unconformities were identified in the Cretaceous interval in the Colombian portion of the POFB, these surfaces are laterally continuous, can be regionally correlated and represent fluctuations in sea level through geological time. The facies assemblages deposited during the changes in sea level are genetically related within a chronostratigraphic or geologic-time framework (Slatt, 2006).

A stratigraphic interpretation was made for 300 wells based upon GR response and core analysis; according to the patterns of this data, three type of surfaces were picked: Flooding Surfaces (FS), Maximum Flooding Surfaces (MFS) and Sequence Boundaries (SB). In this paper it is proposed that the Cretaceous section in the Putumayo basin can be subdivided into five depositional cycles which correspond to the scheme presented for the Ecuadorian part of the MOP basin (Figure 11). Cycles 1 and 3 correspond to sequences of 2nd order whereas Cycles 2, 4 and 5 correspond to sequences of 3rd order, all these cycles have minor order sequences superimposed (Figure 12).

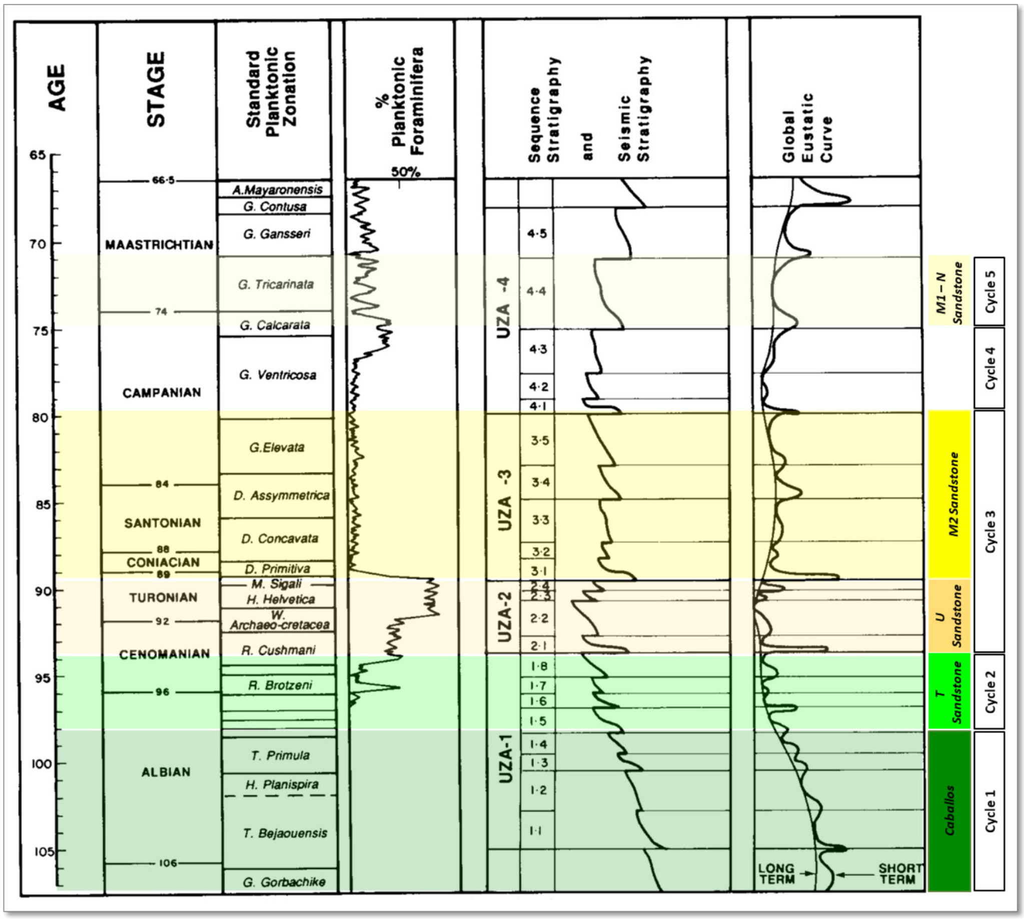

Figure 12. Sequence stratigraphy and global eustatic curve of the mid-Late Cretaceous. Modified from Hart, 1990.

The Cretaceous Megasequence was deposited during a marine transgression, and it can be described, in terms of sequence stratigraphy, as a succession of Lowstand System Tracts (LST), Transgressive System Tracts (TST) and Highstand Systems Tracts (HST). The base of the Cycle 1 is clearly identifiable by a SB which records a period of erosion after the deposition of the Precretaceous volcano-clastic section, then the fluvial basal section of the Caballos Formation (LST1) was deposited filling the previously eroded areas. Next a marine transgression initiated and deposited the TST1 which correspond to the upper section of the Caballos Fm., as the sea level continued rising the calcareous sediments of HST1 were deposited. This was followed by a relative sea level fall that led to the beginning of a new cycle where part of the sediments of the preceding HST were eroded forming a SB. This cyclicity continued up to the Maastrichtian letting the deposition of the overlying cycles which have the same stratigraphic configuration as Cycle 1.

Shale Volume analysis

Shale volume was calculated for 120 wells using the Gamma Ray (GR) log since it is an indicator of the clay content. Clean sand and shale cutoffs (30°API and 115° API) were defined for the Cretaceous siliciclastic reservoir to obtain a general and regional overview of the distribution of the best facies based on their shale content. Since GR logs were not available for older wells it was necessary to use Spontaneous Potential (SP) logs instead and calibrated them with the ditch sample description in an individual case basis. Those wells with SP logs were included to cover areas of the basin where no other data was available. The volume of shale was used to estimate the Net to Gross (NTG) ratio and then to construct NTG maps which were interpreted as pseudo facies maps, assuming that rocks with a higher sand volume were deposited by traction process with predominantly high energy, whereas rocks with higher shale volume were deposited by fall-out process where low energy controlled the depositional environment.

RESULTS

Siliciclastic reservoirs distribution (Isopach and facies maps)

The sequence stratigraphic framework established for the northern part of the POFB was the foundation to construct regional isopach and pseudo facies maps for each one of the Cretaceous siliciclastic reservoirs. This led to subdivide the strata in terms of their genetical relationship instead of a mere lithological correlation, capturing, then, all the changes in facies and thickness.

The Cretaceous sequence in the POFB has a basin-wide distribution, onlapping and pinching-out against the igneous-metamorphic basement towards the East, where the Florencia High is present (Figure 13). As the units become younger, their limits of deposition shift to a more distal position towards the East of the basin. This limit of deposition was defined based on seismic interpretation and well control.

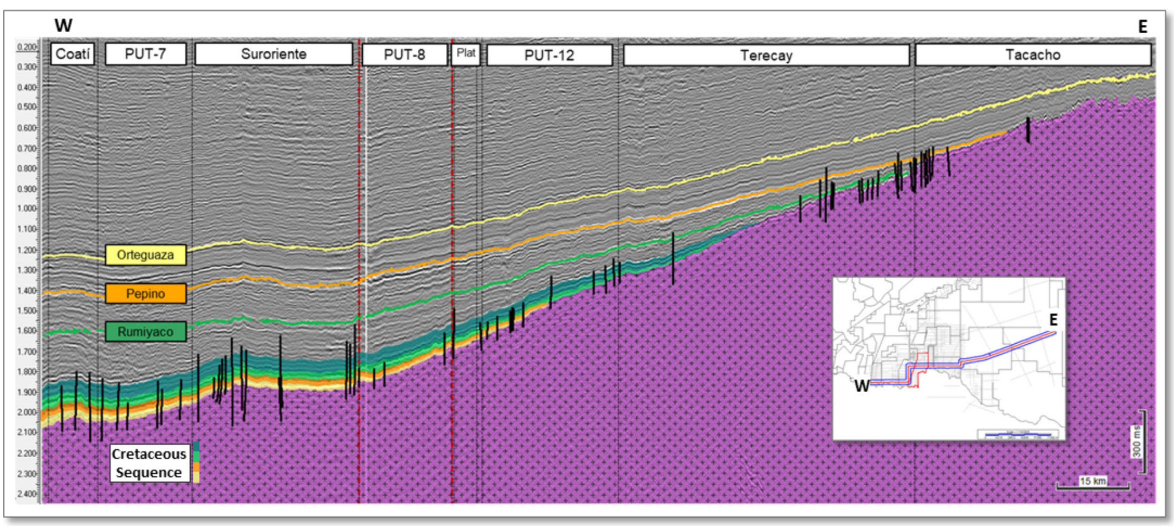

Figure 13. Composite seismic line showing the distribution of the Cretaceous sequence in the Putumayo basin.

The Caballos Formation (corresponding to LST1 and TST1) is the one with the most restricted distribution in the POFB, since its upper member represents just the beginning of the marine transgression. The thickest interval may reach up to 360 ft in the western part of the POFB, where the accommodation space was greater, and it thins towards the east where the Caballos Formation pinches-out against the basement. The NTG map suggests a better quality of the reservoir towards the western Putumayo basin and northern Oriente basin (Figure 14).

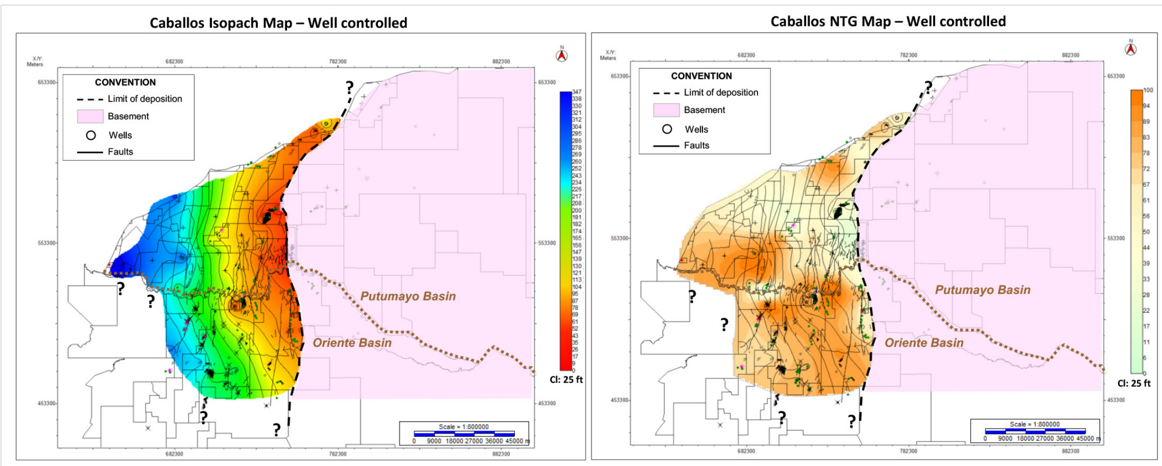

Figure 14. Distribution of the Caballos Formation in the northern POFB.

The T Sandstone (corresponding to HST1 and LST2) represents the first siliciclastic interval of the Villeta Formation. In the Putumayo area, the thickest sediments were deposited towards the western margin of the basin where this interval is around 100 ft thick, however in the northern Oriente area, the T Sandstone is significantly thicker reaching up to 200 ft. The NTG analysis suggests that this reservoir has the better facies in the central area and in the proximity of its pinch-out (Figure 15)

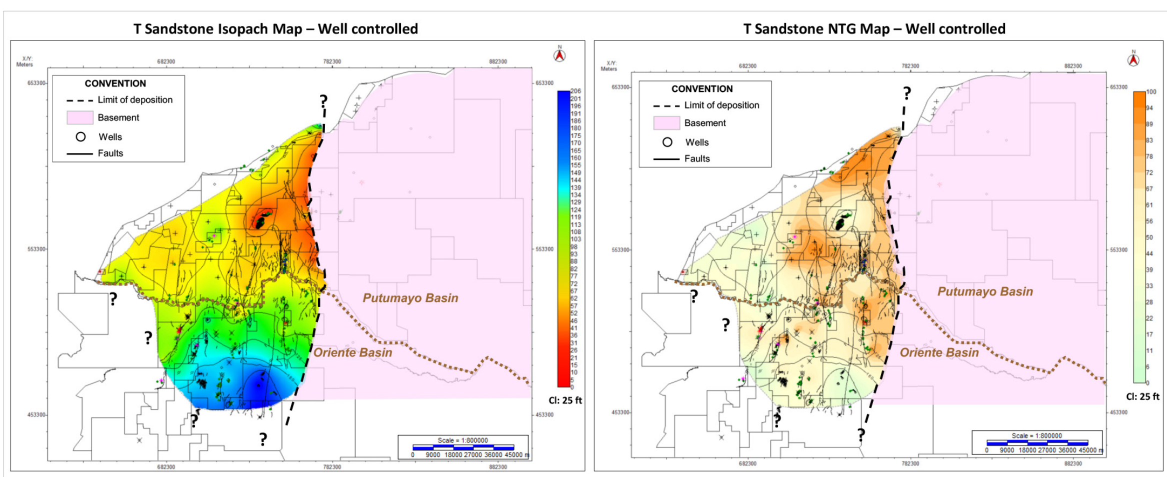

Figure 15. Distribution of the T Sandstone – Villeta Formation in the northern POFB.

The Lower U Sandstone (corresponding to LST3) has a central corridor, that extends in South to North direction, where the sediments range in thickness from 70 ft, in the Putumayo basin, to 140 ft, in the Oriente basin. The facies are distributed in a very similar trend, where the facies with higher sand content are in the central corridor but also in the northeast area of the Putumayo basin (Figure 16).

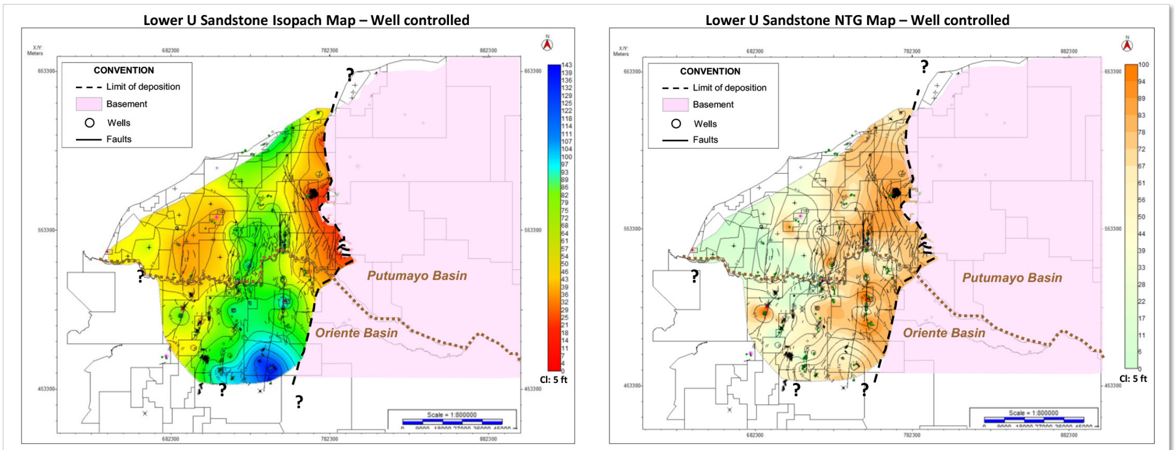

Figure 16. Distribution of the Lower U Sandstone – Villeta Formation in the northern POFB.

The Upper U Sandstone (corresponding to TST3) exhibits a similar trend for the thickness distribution, if it is compared to the Lower U Sandstone, there is a central corridor of thicker sediments, extending from South to North where this interval varies its thickness from 110 ft to 70 ft, respectively. On the other hand, the reservoir with better facies is present mainly in the northern Putumayo close to the limit of deposition of this unit (Figure 17).

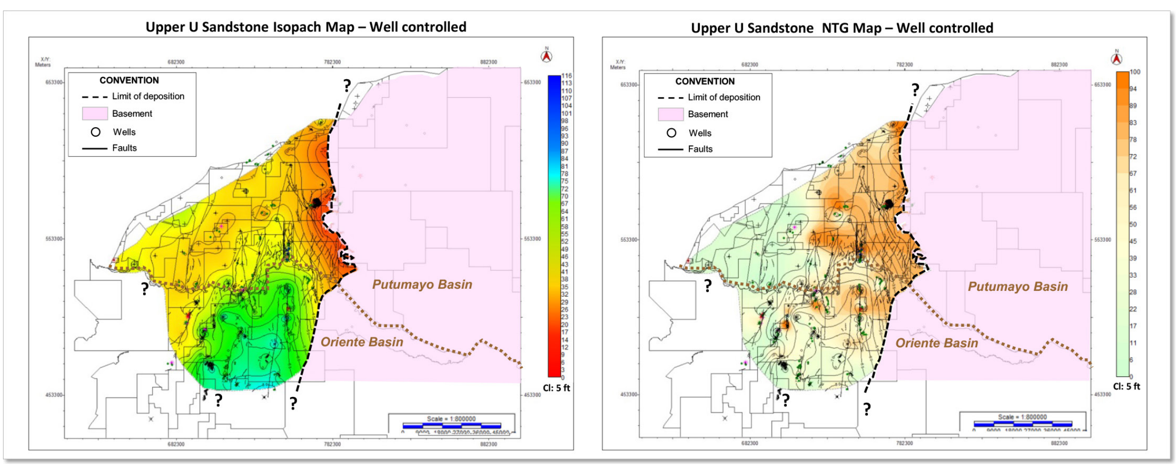

Figure 17. Distribution of the Upper U Sandstone – Villeta Formation in the northern POFB.

The M2 Sandstone (corresponding to HST3) exhibits a particular behavior differing from the underlying units. There is a marked change in thickness towards the center of the POFB extending in South-North direction, where this unit thins considerably towards the western POFB, and it is probable that this change in thickness was highly influenced by the tectonic processes occurring at the time of the deposition. The NTG map shows a different pattern, as well, indicating that the best facies are restricted to a small area close to the limit of deposition towards the Northeast part of the Putumayo basin (Figure 18).

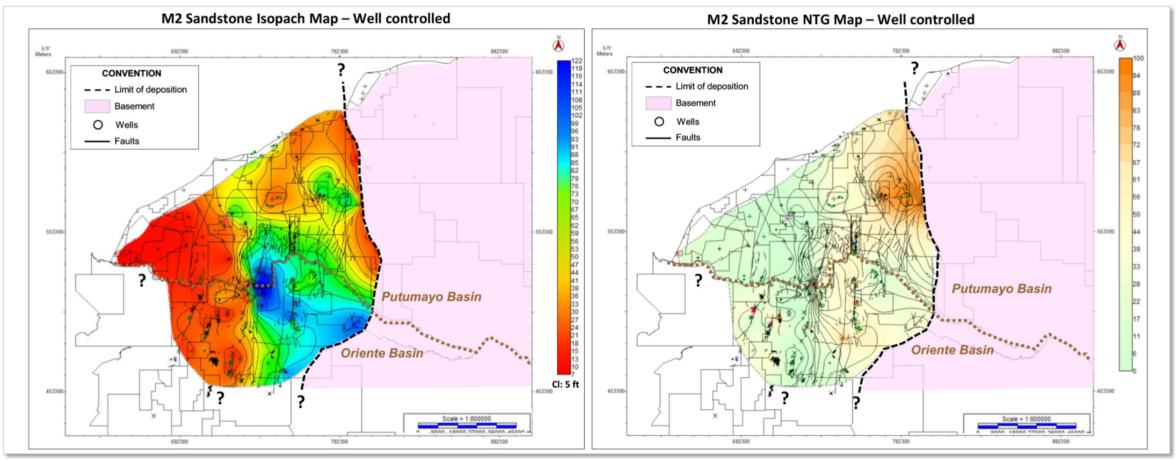

Figure 18. Distribution of the M2 Sandstone – Villeta Formation in the northern POFB.

Structural Framework

The POFB has had a geological evolution framed by different tectonic episodes that have transformed it from a rift-type basin (Triassic-Jurassic), passing to a back-arc basin during most of the Cretaceous, to a foreland-type basin from the Late Maastrichtian (Aguilera, 2006).

According to Fechi, *et al.*, 2022 the basin shows evidence of four major tectonic events, successive and over imposed as follows: (1) Rifting (Triassic to Campanian) forming grabens/accommodation space for the entire Cretaceous sequence, (2) Pre-Andean (Middle Eocene) with the first reverse fault reactivation process, (3) Andean Orogeny (Upper Oligocene to Upper Miocene) as the main Andean uplift event and (4) Late Andean (≈3 My) as a compressive-transpressive event oblique to the main tectonic transport direction.

The structural interpretation performed over the available seismic (2D & 3D) evidenced several fault planes, most of them with local expression, but some others as regional systems in the POFB. Figure 19 shows the relation between faults at basement level and the interpreted limits for Cretaceous reservoirs deposition.

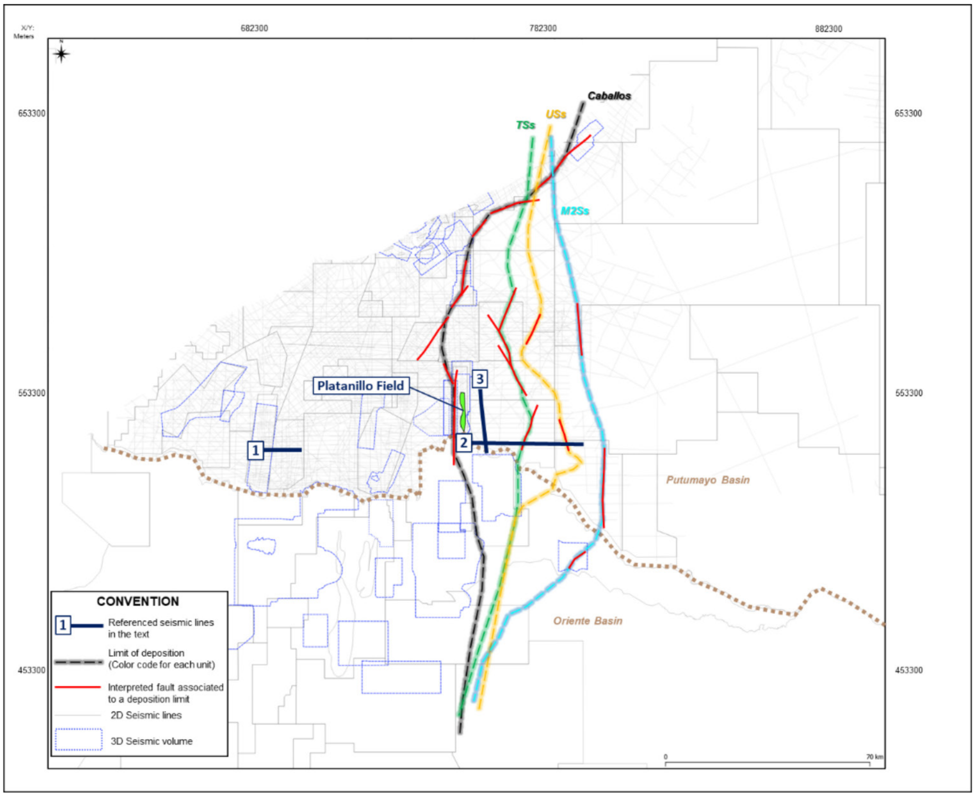

Figure 19. Relation between Cretaceous depositional limits and interpreted fault planes.

The following seismic lines offer some examples of the tectonic control in the Cretaceous sedimentation (Location in Figure 19). In the western part of the basin (deep foreland) the geometric relationship between highs and lows for the accumulation of the basal Cretaceous Caballos Formation is shown in Figure 20. To the east of the POFB (Figure 21) the Cretaceous sequence thins progressively, representing the limit of deposition for most of the Cretaceous reservoirs. Finally, in the central part of the basin (Fig. 22), a similar situation can be seen but, in perpendicular direction compared to the previous seismic sections (Figs 20 & 21).

Sedimentary Paleoenvironment and Reservoir Potential

The Cretaceous siliciclastic reservoirs were deposited in low energy marine-coastal environments (estuaries). According to the core analysis, the majority corresponds to estuaries dominated by tides. Wave action is practically non-existent. This determines the distribution and direction of the reservoirs, which were oriented perpendicular to the coastline.

Two main sections may be recognized: the upper, with tidal interaction, and the lower, with fluvial influence.

In the upper one, deltaic (bay head) and mouth bar deposits develop.

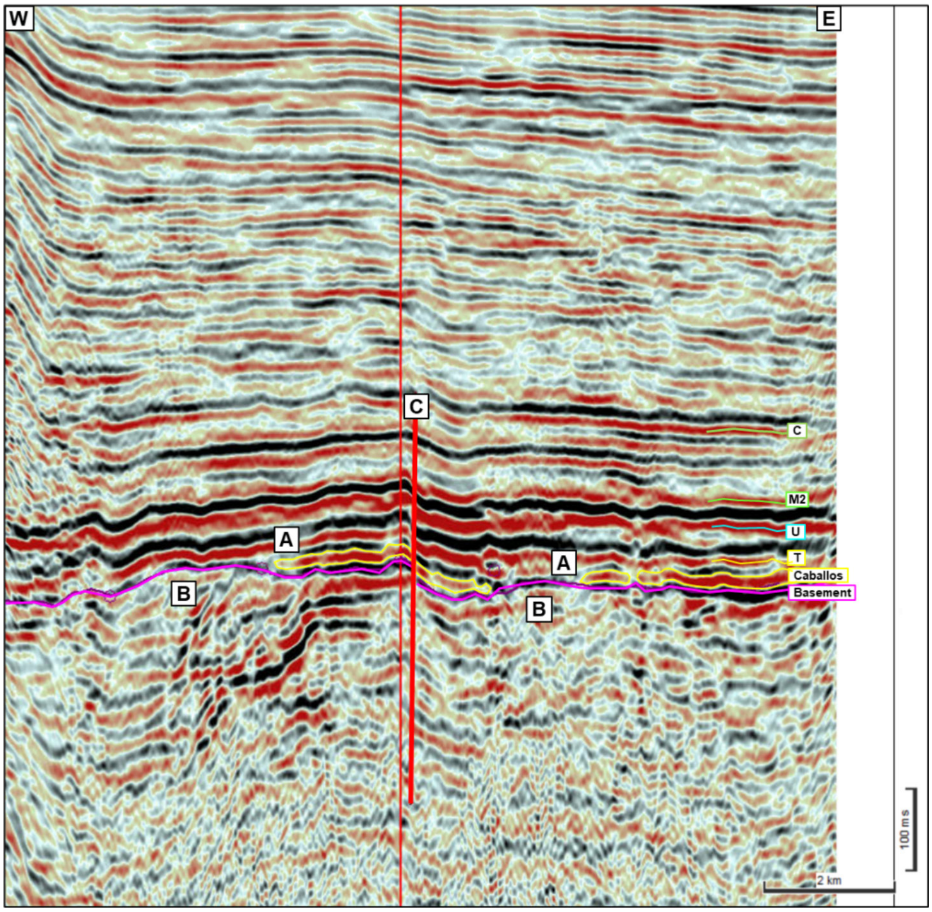

Figure 20. Line 1: Caballos Fm. Basal Cretaceous deposits (A) controlled by paleohighs (B) and lately affected by faulting (C).

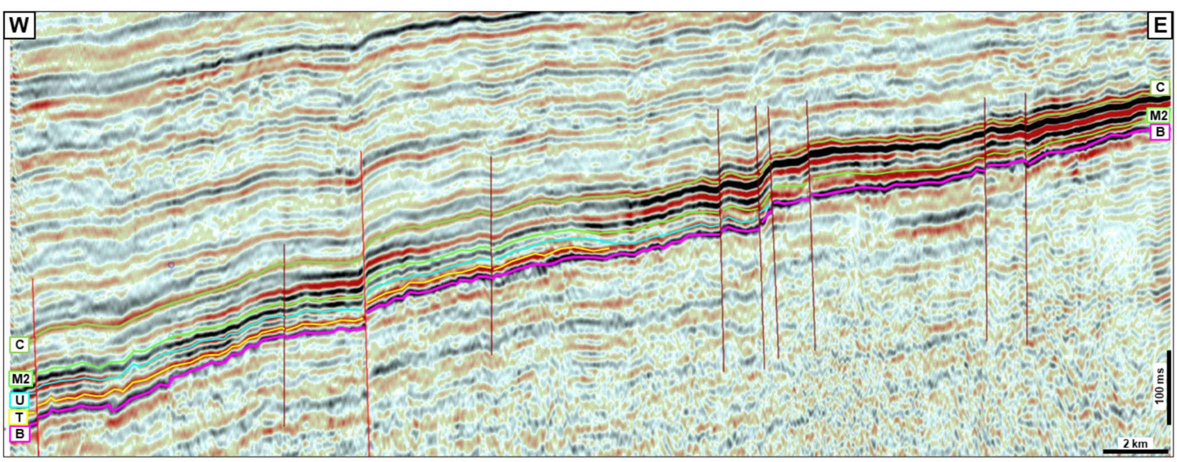

Figure 21. Line 2: Seismic line showing the extension and tectonic control for Cretaceous reservoirs. B: Basement, T: T sandstone, U: U sandstone, M2: M2 sandstone and C: Top Cretaceous.

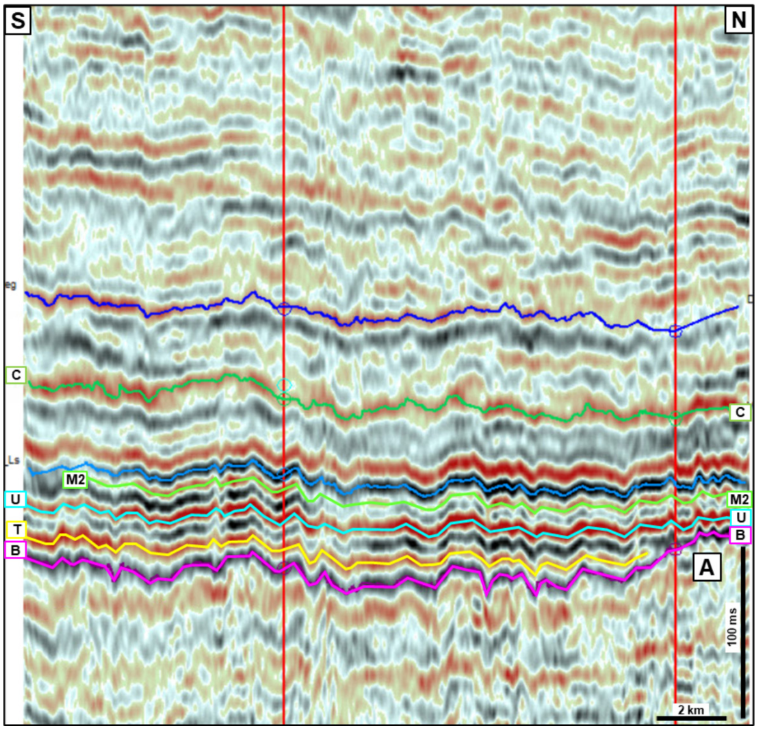

Figure 22. Line 3: Seismic line in a south-to-north direction showing the tectonic control for Cretaceous reservoirs. A: Basement Paleohigh, B: Basement, T: T sandstone, U: U sandstone, M2: M2 sandstone and C: Top Cretaceous.

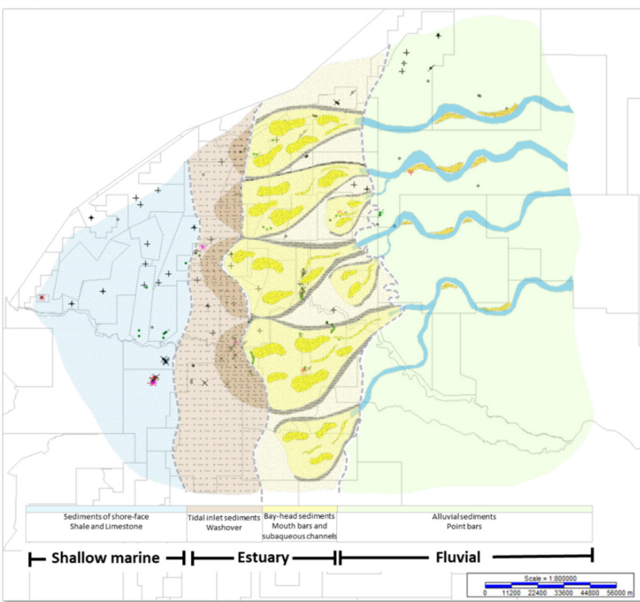

Figure 23. Conceptual models for the paleoenvironment of deposition for the Cretaceous siliciclastic reservoirs of POFB.

The lower one is characterized by sinuous course deposits with point-bars reworked by the tide, constituting ideal reservoirs for hydrocarbons accumulation.

In the POFB, the sediments with sandier facies correspond to bay head delta deposits where there is an interaction between subaqueous channels and mouth bars. As the distance from the coastline increases, washover sediments, with a higher silt content, were deposited. Towards the western margin of the POFB, in a deeper position, calcareous and shaly sediments were deposited (Figure 23). These observations are supported by the distribution of NTG presented in the regional maps.

Regional Prospective Areas Maps were constructed for the Cretaceous siliciclastic reservoirs based on the analysis of the isopach and NTG maps (Figure 24). These maps offer a regional view of the regions with high, moderate, and low potential to find reservoirs with good petrophysical conditions to accumulate hydrocarbons for each reservoir, suggesting the areas of the POFB where a more detailed evaluation should be carried out.

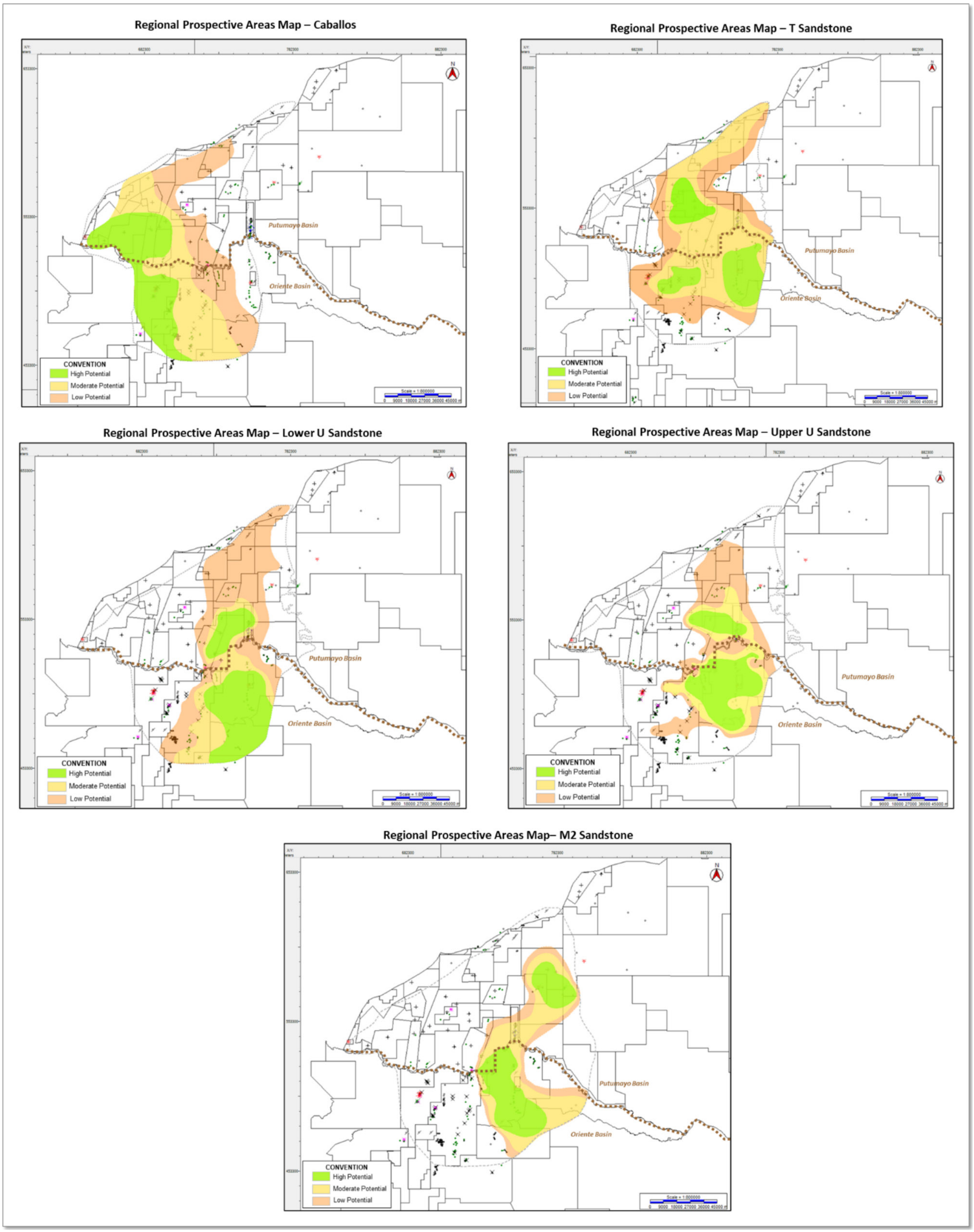

Figure 24. Regional Prospective Areas Maps for the Cretaceous Siliciclastic Reservoirs in the POFB.

Thickness, NTG and sedimentary environment maps were used to define these prospective regions. The limits to delimit them are qualitative and porosity was not included as an element to define these areas.

DISCUSSION AND CONCLUSIONS

The Cretaceous siliciclastic reservoirs were deposited in a low energy marine-coastal environment, onlapping and pinching-out against the igneous-metamorphic basement towards the East (Florencia High). The available core shows evidence of an estuarine setting dominated by tides where the wave action is almost absent.

The sequence stratigraphic framework led to the definition of five stratigraphic cycles of 2nd and 3rd order with minor order sequences superimposed, deposited during a marine transgression that lasted around 40 my. The sea level fluctuations during this period led to the deposition of a sandstone overlain by limestone – silty intervals stratigraphic pattern that repeats over the entire transgression.

The tectonic events present in the POFB imply a very important control in sedimentation for the Cretaceous sequence, due to the formation of horst-graben successions, paleohighs and tectonic inversion structures.

Prospective areas for the presence of reservoirs were proposed based on the integrated core, sequence stratigraphy and shale volume analysis. This offers a regional view of the potential to find hydrocarbons accumulations in the Cretaceous siliciclastic reservoirs in the POFB. Those prospective areas are supported, as well, by the results of the wells drilled in the region.

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REFERENCES

Aguilera, R. (2006). Modelos de Generación y Migración de Hidrocarburos en la Cuenca del Putumayo. IX Simposio Bolivariano "Exploración Petrolera en las Cuencas Subandinas". Cartagena.

ANH, (2009). Interpretación de datos de Aerogravimetría y Aeromagnetometría en la cuenca Caguán – Putumayo. Septiembre de 2009. Agencia Nacional de hidrocarburos, Bogotá, Colombia, Sur América.

ANH, (2011). Montenegro, G., Barragan, M., Caguán and Putumayo Basins. In Cediel, F. (ed), Petroleum Geology of Colombia, vol 4.

Baby, P., Rivadeneira, M., Barragán, R., Christophouls, F., 2013. Thick-skinned tectonics in the Oriente foreland basin of Ecuador. Geolog. Soc. Spec. Publ. 377 (1), 59-76.

Barragan, R.F., Christophoul, H., White, P., Baby, M., Rivadeneira, F., Ramírez, P. and Rodas, J., 2004. Estratigrafía Secuencial del Cretácico De La Cuenca Oriente del Ecuador. (Eds) In: La Cuenca Oriente. Geología y Petróleo, pp. 45-68.

Beltrán, W., Espitia, W., Bello, D., Arias, J., Higuera Díaz, I., 2015. Structural styles of the southern Putumayo Foreland Basin, northern Andes, Colombia. In Zamora, G., Mora, A. (eds.), Andean Structural Styles: A seismic Atlas, pp 227-234.

Fechi, Y., Rossi, G., Rodríguez, N., Gómez, A., Etcheverry, A., 2022. Tectonic evolution, structural provinces & tectono-stratigraphic sequences in the Putumayo Basin Foothills, Colombia. XII Congreso de Exploración y Desarrollo de Hidrocarburos, IAPG, Mendoza, Argentina.

Hart, M.B., 1990. Cretaceous sea level changes and global eustatic curves; evidence from SW England. Proceedings of the Ussher Society, 7, 268-272.

Kairuz, E. C., Córdoba, F., Moros, J., Calderón, W., & Buchelli, F. 2000, Sistemas petrolíferos del Putumayo, Colombia. Proceedings of the VII Simposio Bolivariano (pp. 525–532), Bogota, Colombia.

Mathalone, J.M.P., and Montoya R., M., 1995, Petroleum geology of the sub-Andean basins of Peru, in Tankard, A.J., Suarez Soruco, R., and Welsink, H.J., Petroleum basins of South America: American Association of Petroleum Geologists Memoir 62, p. 423–444.

Mora, A., Mantilla, M., Freitas, M., 2010. Cretaceous Paleography and Sedimentation in the Upper Magdalena and Putumayo Basins, Southwestern Colombia. Article #50246, International Conference and Exhibition AAPG, Rio de Janeiro, Brazil.

Pachón, L., 2013. Subsurface mappoking and 3D flexural modeling of the Putumayo foreland basin, Colombia. Master of Science Thesis. 153 p University of Houston. USA.

Rodriguez, G.; Zapata, G.; Velázques, M. E.; Cossio, U.; Londoño, A. C., 2003. Geología de las planchas 367, 368, 389, 390, 391 y 414. INGEOMINAS. 165 p. Bogotá.