Upper Cretaceous in the Middle Magdalena Valley, Colombia, South America: A New Exploratory Target in an Old Mature Basin*

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Abstract

Oil exploration in the Middle Magdalena Valley Basin “MMVB” in north central Colombia, South America has, since its beginnings in 1916 when the Tropical Oil Company drilled the Infantas-1 well in the “De Mares” Concession (Figure 1), traditionally been focused on the search for continental and transitional clastic reservoirs of Cenozoic age. Later in the 1950’s and 1960’s some companies started drilling deeper looking for Lower Cretaceous marine reservoirs, especially those of calcareous composition (i.e. the Totumal Field drilled by Texas Petroleum Co.). Few wells were successful in those exploration campaigns targeted at Lower Cretaceous plays (Figure 1). In the past, the oil industry considered the Upper Cretaceous formations both as seal rock for Lower Cretaceous reservoirs and as economic basement for Lower Paleocene and Neogene exploratory plays.

This paper is based on a detailed review of the geological data of old wells drilled within and near the exploration and production areas contracted by Petrolatina Energy Plc in this Basin (Figure 3). In addition, an exhaustive analysis of existing well logs, well tests, pressure data, oil and gas shows, sidewall core samples, and the study of drilling problems detected in well history reports of these areas was completed. All this information, when assembled and analyzed, pointed to unrecognized oil potential in the Upper Cretaceous reservoirs of this basin. Based on this concept a stratigraphic and sedimentologic analysis was conducted to understand and detect reservoirs in the Upper Cretaceous to Lower Paleocene formations.

The basic stratigraphic analysis indicated that an unconformity contact is not present between the Maastrichtian and Lower Paleocene, that interpretation was stated previously in general terms by previous authors, such as Morales (1958), Rolón and Toro (2003). Based on interpretation of seismic sequences, the absence of an unconformity between the Maaestrichtian and Paleocene was also confirmed.

Seismic interpretation and stratigraphic analysis indicate that an important relative fall of sea level and an increase of sediment supply have had implications for deposition of the reservoirs in the Upper Cretaceous in this part of the basin. That, in turn, produced a change in the lithology and character of the reservoirs in this part of the basin. These begin at the bottom with marine shales and pass upwards into tidal sandstones and finally end near the top with estuarine channel sands. Wells recently drilled by Petrolatina Energy confirm that the contact from Maastrichtian rocks to Paleocene rocks is clearly transitional.

Petroleum System

Hydrocarbons generated in the northern part of the Middle Magdalena Valley Basin "MMVB" originated in marine source rocks, mainly calcareous shales and limestones, of the Aptian-Valanginian Basal Calcareous Group (Tablazo Fm., Paja Fm. and Rosablanca Fm.). These source rocks generated mature oil in the deepest parts of the basin. That is suggested by previous authors such as R. Aguilera (2009), and it is interpreted that this oil migrated mostly vertically through the planes of reverse faults and filled reservoirs by migrating via carrier beds. Together, the definition of a new Upper Cretaceous reservoir based on recent drilling results and improved understanding of the oil generation/migration mechanism from the "Basal Calcareous Group-Umir Formation" allows us to propose a new petroleum system which is *Aptian-Valanginian-Maastrichtian* in age. This new understanding is based on the geological studies conducted recently and the exploration results derived from the eleven wells drilled on the Petrolatina blocks, five focused in the Upper Cretaceous (Figure 4).

Petrolatina Energy Plc started an aggressive exploratory campaign to understand the elements of the new petroleum system in the basin in 2007. Although the Company had been active in the area for some years, new investment funding received at that time allowed a fresh approach. Initially the search for new traps focused on initial acquisition of regional 2D data and exploratory 3D seismic data to illuminate the main unconformities and structures of the basin. This process also defined the migration connections, such as faults, between the reservoir and source rock units. Working on the stratigraphic interpretation of this seismic data allowed us to confirm the transitional contact below the Paleocene rocks as well as establishing the presence of Miocene and Eocene unconformities. The gathering and interpretation of all of these facts resulted in the identification of many exploratory plays of the Upper Cretaceous reservoirs. As noted above, a proposed new petroleum system results from the identification, based on drilling results, of the presence in a new reservoir. Petrolatina Energy Plc geologists informally name that reservoir as the "Umir Upper Sand". Support for the proposed new petroleum system is based on the primary geological tools of biostratigraphy and stratigraphy, as well as on the results of petrographic, sedimentologic and petrophysic studies on the newly found reservoir. The main points of this work are described here. Based on micropaleontologic and palynologic biostratigraphic analysis it was determined that these rocks are Maastrichtian in age and were deposited in a coastal to shallow marine environment with tidal and marsh influences. Figure 2 illustrates, from the base to the top, the composition of the characteristic foraminifera and palynomorphs that are present in the cored interval in the 2009 Petrolatina Colón 2 well, which is located in the La Paloma Block.

Reservoir Definition

Core and thin section petrographic analysis from the Colon 2 well resulted in the definition of five petrofacies, arranged in three groups. The first group consists of sandstone with siderite characterized by low clay contents, framework grains agglutinated partially by siderite, moderate to poor packing, 16% porosity in thin section, high effective core porosity (22% to 30.7%) and high absolute permeabilities (443 to 1190 mD) based on petrophysical core analysis. These petrofacies include subarkoses with siderite, feldspathic lithoarenites to lithic arkoses with siderite laminae and subarkoses with laminae of siderite and bioclasts. The second petrofacies group comprises laminated mudstones/sandstones with moderate reservoir characteristics with porosities ranging from 8.9% to 12.7% in thin section and 15.6%-20.7% are obtained by petrophysical analysis. Absolute permeabilities are much lower (20-65mD) than first group. The third group consists of bituminous claystones and laminated lithic muddy sandstones. These have the lowest porosities (15.7%-18.3%) and permeability values (3.3- 20 mD). This third petrofacies also includes bituminous claystones and mudstones with laminae or lenses of lithoarenites.

The rocks in the study area are characterized by low compositional maturity with a high content of unstable minerals and lithics. Decomposition of these materials produce clays that diminish porosity and permeability. However, dissolution of these components generates compensating secondary porosity that increases porosity and pore connectivity. Clays are predominantly illite and kaolinite. Smectite and chlorite were found in minor proportion. Abundance of mixed layered illite/smectite in relation to total clay content varies in a wide range of 12-41%; a very low content of 3% is found locally. The illite-smectite association shows a predominance of 70-80% of illite over smectite. Since the smectite content is low, drilling and production problems potentially resulting from the contact of clay with water are minimal.

The stratigraphic understanding of the reservoir has been greatly enhanced by the study of a core from the Colón-2 well. The cored section comprised part of the “Umir Upper Sand” and was examined in order to describe and log in detail the textural and compositional sedimentary features and sedimentary structures to allow us to conduct analysis (Figure 5) and discern depositional environments (Figure 6). The cored interval corresponds to part of the Umir Formation and consists mainly of mixed or heterolithic sandstone-mudstone facies and mudstone facies, and in minor part sandstones facies. The facies show a general fining upward transition. Heterolithic or interlaminated sandstone-mudstone facies occur throughout the whole and are mostly non-bioturbated. They comprise flaser, flaser wavy, wavy, wavy lenticular, undulose, and horizontally interlaminated, organic matter-rich sandstones and mudstones in various proportions. Mudstone facies are predominant in the upper part of the reservoir core, but sparse in the middle and lower cored section, and they consist of non-bioturbated to bioturbated and locally very highly bioturbated organic matter rich mudstones and all are essentially organic matter rich with some carbonaceous organic matter rich sections. The mudstone facies are silty to somewhat sandy, dark to medium gray in color, non-calcareous, and are very locally fossiliferous. The sandstone facies occur only in the middle and lower part of the reservoir, and are mostly non-bioturbated to slightly bioturbated. Non-bioturbated sandstones contain horizontal lamination, undulose lamination, undulose lamination with intraclasts, ripples and trough planar cross-laminated sandstones with intraclasts.

The low bioturbated sandstones occur sparsely in the middle and lower part of the reservoir and exhibit undulose lamination slightly inclined with interposed flasers. Sandstone facies are in general light to dark brown, locally gray, dark gray and beige colored, moderately to poorly sorted, with silt and locally fine grain size. The sandstones correspond to essentially subarkose, lithic arkose, arkosic litharenite, and litharenite facies.

The occurrence of low to very highly bioturbated facies, cryptobioturbation, distinct ichnofossils (such as Planolites), distinct resting, feeding and dwelling biogenic structures is interpreted to indicate deposition in a marine influenced environment. Heterolithic (or interlaminated/interbedded) sand and mud units or inclined heterolithic (or interlaminated) sand and mud units or epsilon bedding, flaser, flaser wavy, wavy, wavy lenticular, lenticular and undulose laminations indicate tidally influenced environments.

The sandstone facies seen in the Colón-2 core represent gradational sequences ranging from undulose or ripple to horizontal laminated or trough cross laminated sandstones and locally fining upward to interlaminated sandstone-mudstone facies deposited as intertidal channel fills and tidal creeks with upper accretionary bank environments. In this tidal dominated system, interlaminated mudstone within predominantly sandstone facies with flaser and wavy flaser laminations correspond to intertidal sand flat deposits, interlaminated sandstone-mudstone facies represent intertidal mixed flats, and muddy interlaminated sandstone-mudstone facies and organic matter rich mudstones reflect intertidal mud flats. Carbonaceous organic matter-rich mudstone facies and sequences are interpreted as salt marsh deposits. Inclined heterolithic and inclined undulose sandstone or mudstone facies represent accretional bar deposits (Figure 6).

The reservoir sands of this petroleum system exhibit moderate to good petrophysical properties based on electric logs. Reservoirs mostly comprise thinly laminated sandstones whose volume of clay (Vcl) ranges from 3% to 45% with the higher values in the most laminated intervals. The average effective well log porosity (Phie) is nearly 20%, the log based (Timur method) permeability calculation is about 65mD, and pay zone thickness is up to 30 feet. It is important to note, from an engineering/drilling point of view, that this section is moderately overpressured and that is also reflected in moderate productivity index of about 0.15 bbl/psi. The oil produced is 22° API.

Trap and Seal

The discovery of economic oil production in this new Umir reservoir in the Middle Magdalena Basin has opened up a new frontier for Petrolatina because of the knowledge gained from the trap found in the Colón Field. Although Colón is a structural four way dip closure limited to the east and west by reverse faults (“ low amplitude pop up structure”), the trap has an important stratigraphic component that is expected to control the field limits and hence production and future development. This trap (Figure 7) represents the first seismic expression of an Umir sand reservoir-based field in the basin. The Maaestrichtian to Paleocene thick intertidal mud flat deposits overlying the reservoir in this trap represent an important seal in this petroleum system and could explain the overpressure observed in this formation (approximately 6400 psi at reservoirs depth of 8700 ft).

Conclusion and Recommendations

A new reservoir has been identified, tested and placed in production in the Middle Magdalena Valley Basin in Colombia. This success has opened the door for the exploration of new hydrocarbon reserves in what was previously considered a mature basin. The Colón 1 and Colón 2 wells now produce more than 400 BOPD each on natural flow from the “Umir Upper Sand” in the La Paloma block. The studies conducted by Petrolatina have found that the Umir reservoir sands were deposited in a marine to tidally influenced depositional environment and future exploration for this kind of reservoir facies in different traps in the basin is expected to add significant hydrocarbon resources not previously known or explored for in this part of Colombia.

It is an important recommendation resulting from the recent success of Petrolatina that more studies be conducted to correlate the Umir oil and source rocks facies to confirm the origin of the oil generation and to shed more light on migration pathways. Locally more core data and outcrop section studies are required to develop more accurate stratigraphic models. In terms of future work, Petrolatina also is currently undertaking seismic attributes analysis in the Colón field to integrate the geological model and to provide a basis for future field development.

Acknowledgments

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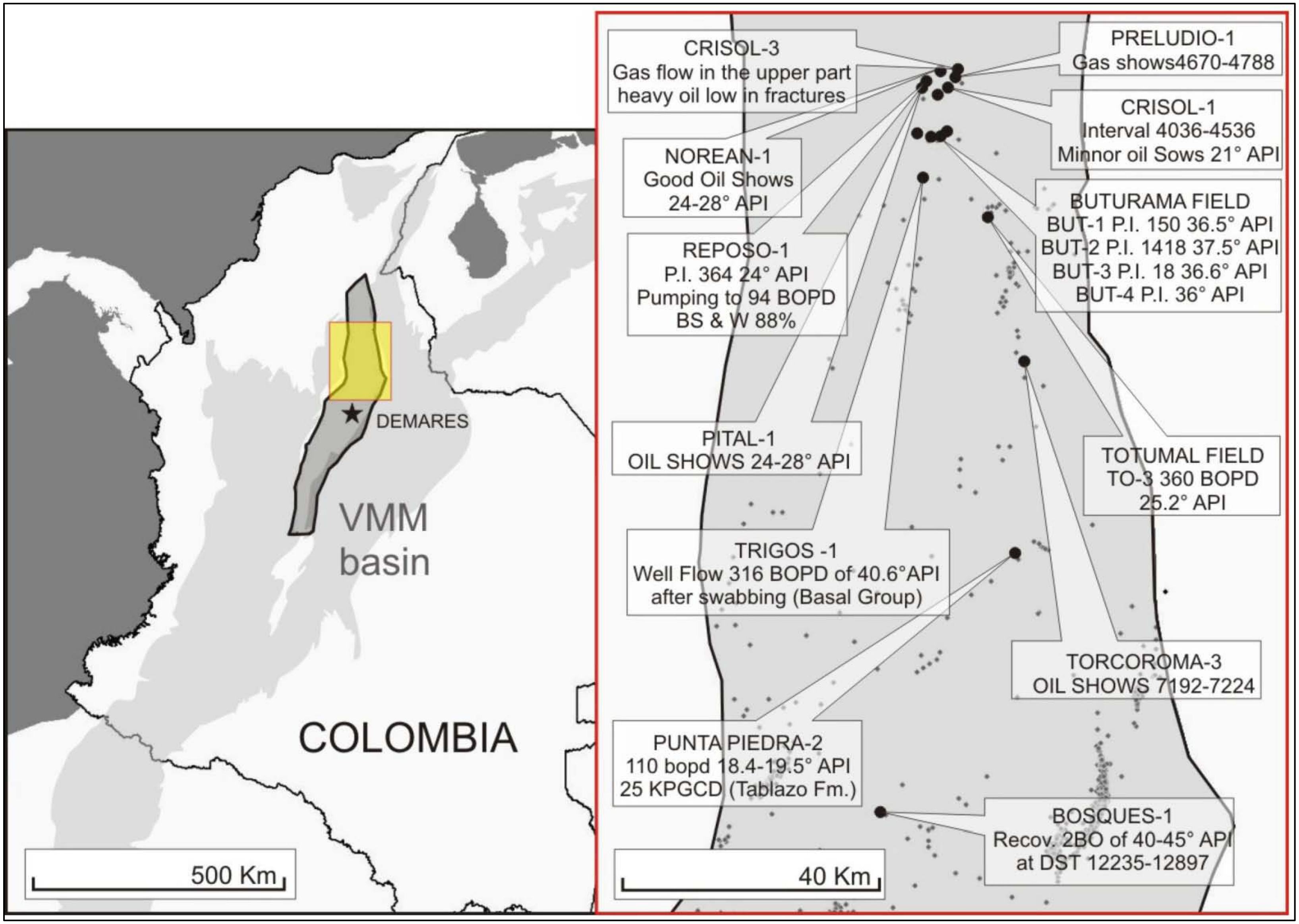

Figure 1. (Left) The location of the Middle Magdalena Basin, and the De Mares concession. (Right) The Pre-Maaestrichtian Oil fields in the middle Magdalena Basin.

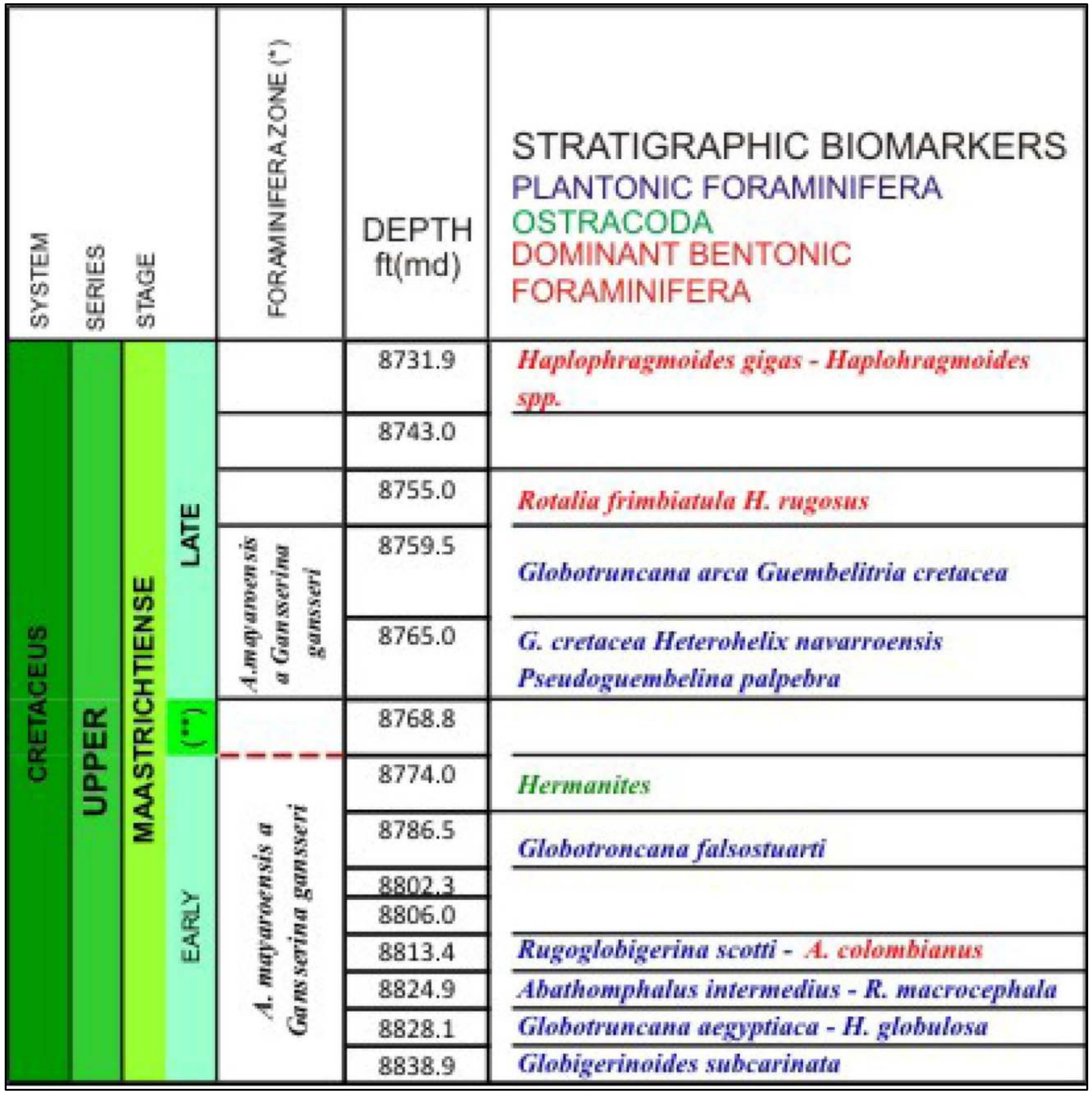

Figure 2. Colón 2 well cored interval from base to top showing the characteristic foraminifera and palynomorphs that are present. This corresponds to late Maastrichtian. At left are the main dominant microfossils and stratigraphic biomarkers.

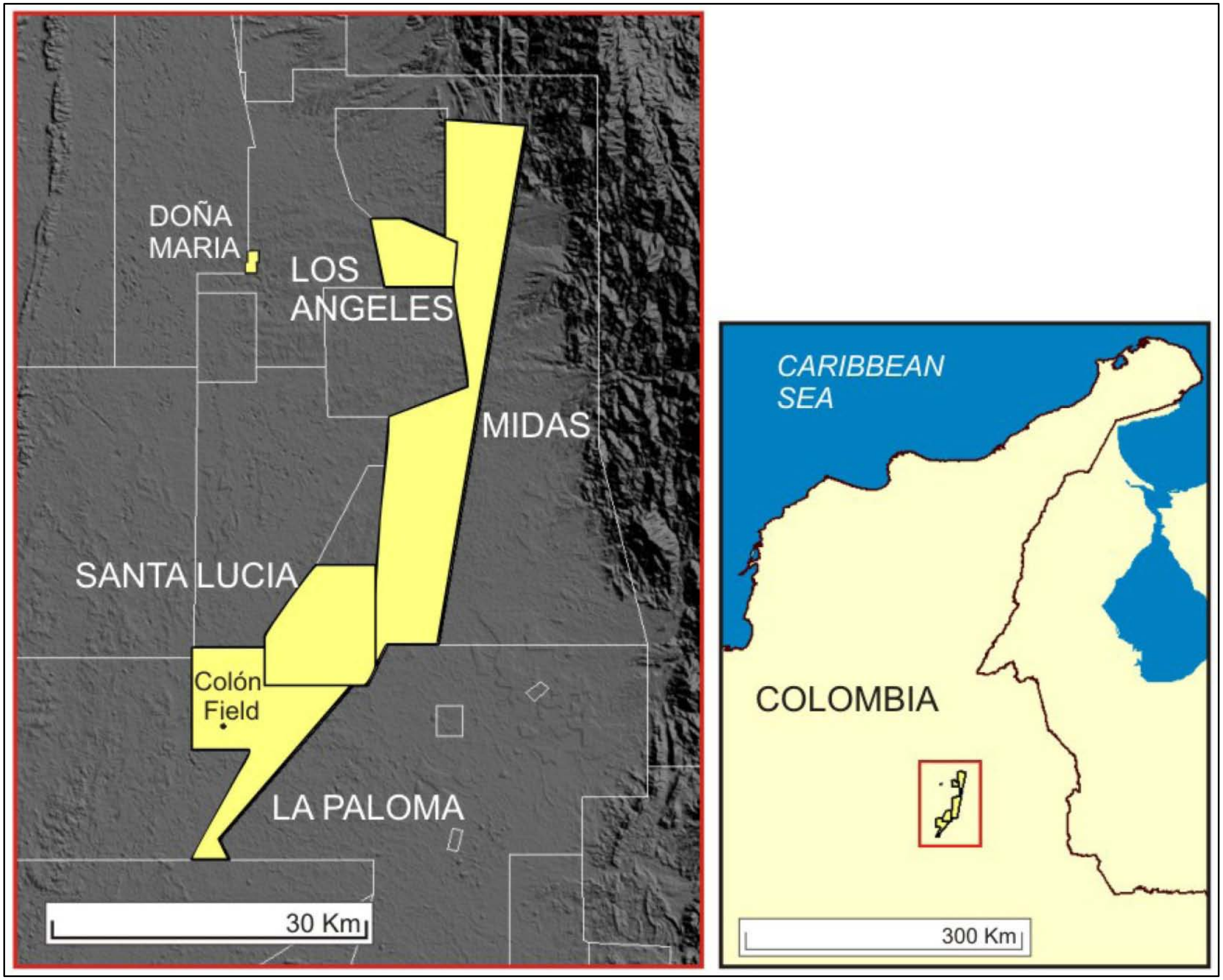

Figure 3. The study area comprising the Petrolatina Energy Plc Exploration and production blocks in the MMVB.

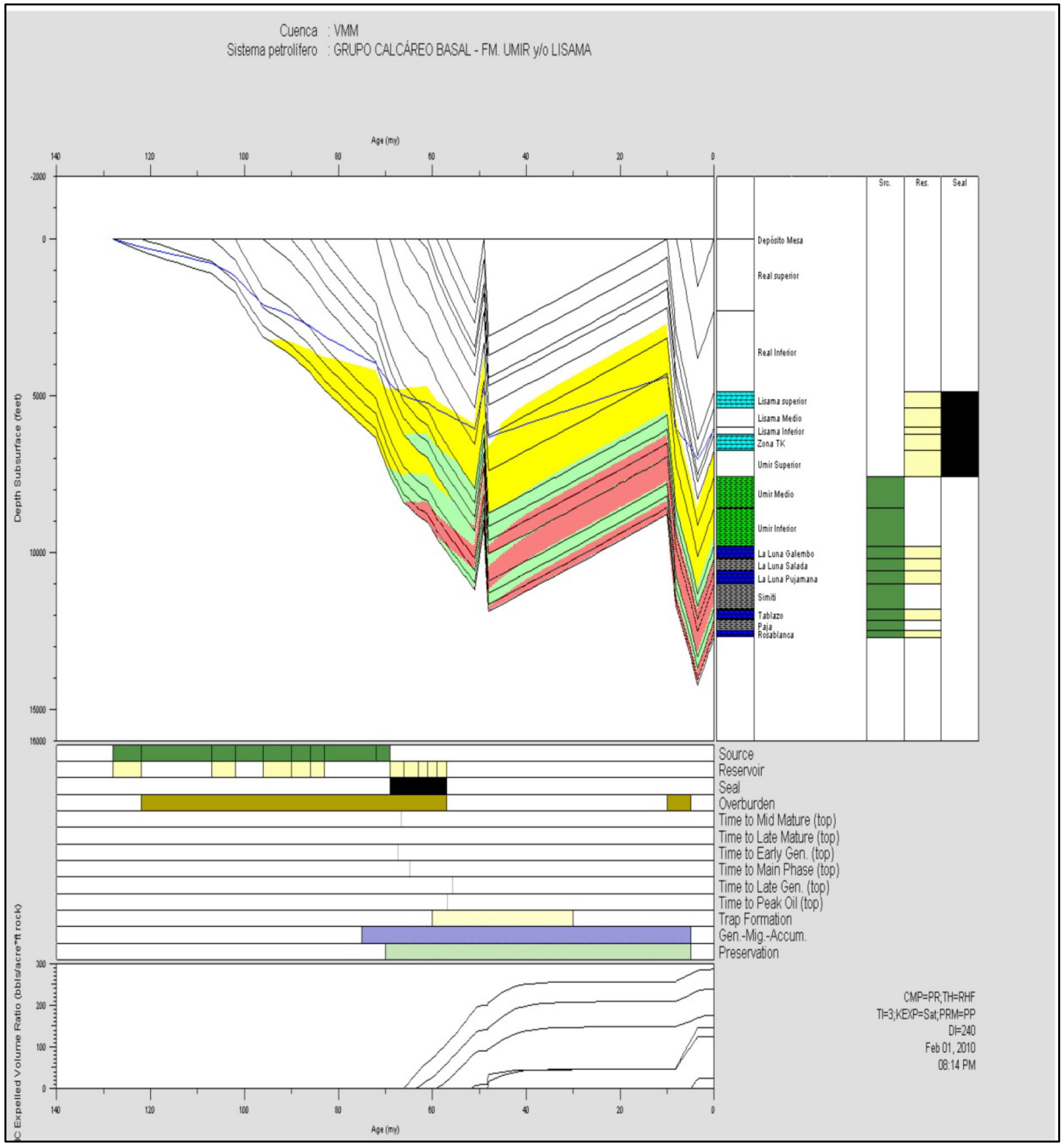

Figure 4. Event charts of the proposed petroleum system “Basal Calcareous Group-Umir”.

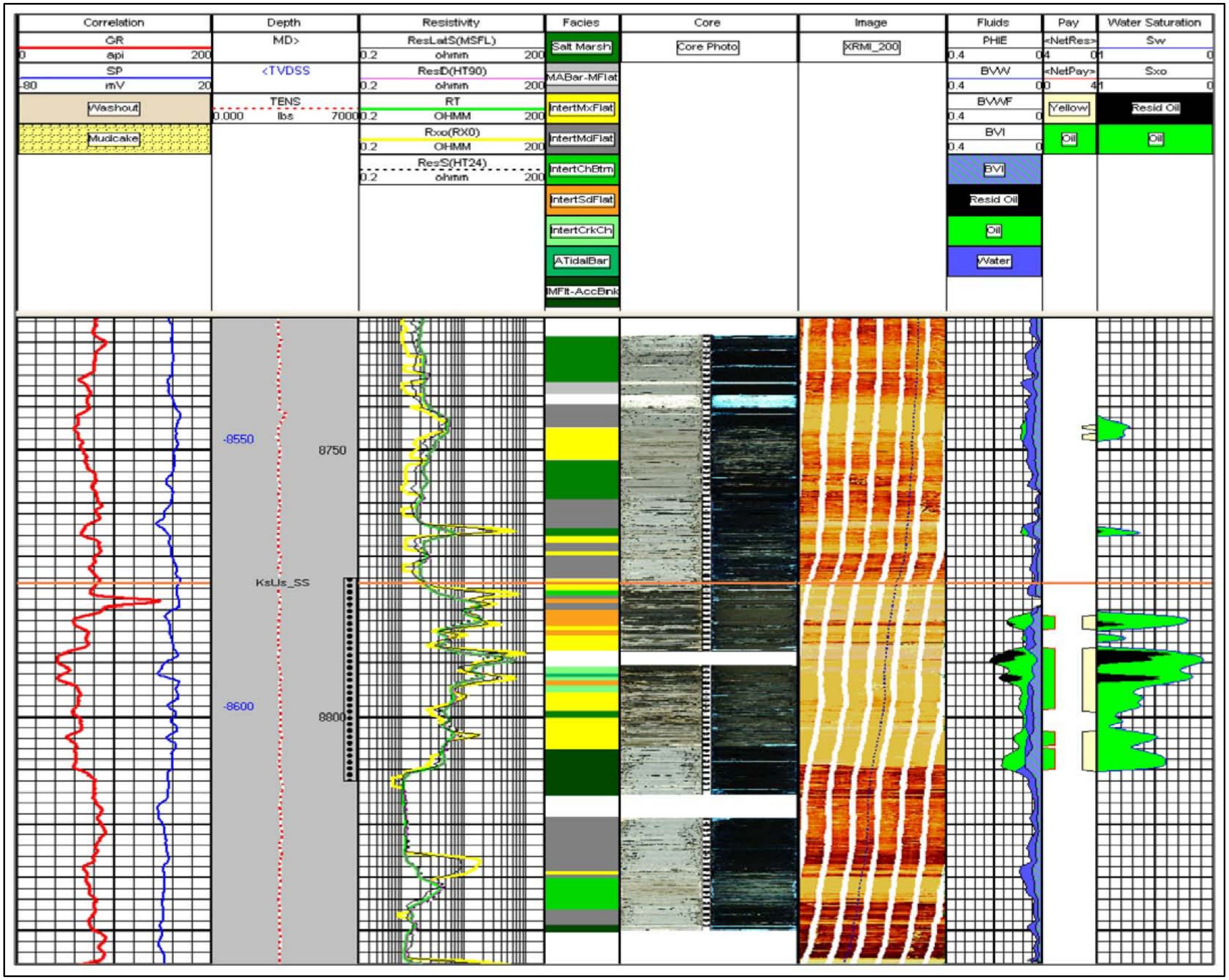

Figure 5. Petrophysical interpretation of the Umir sand reservoir and facies distribution. The best reservoir is related to facies deposited in intertidal sand flats, intertidal channels, intertidal creek channels and intertidal channel bottom environments.

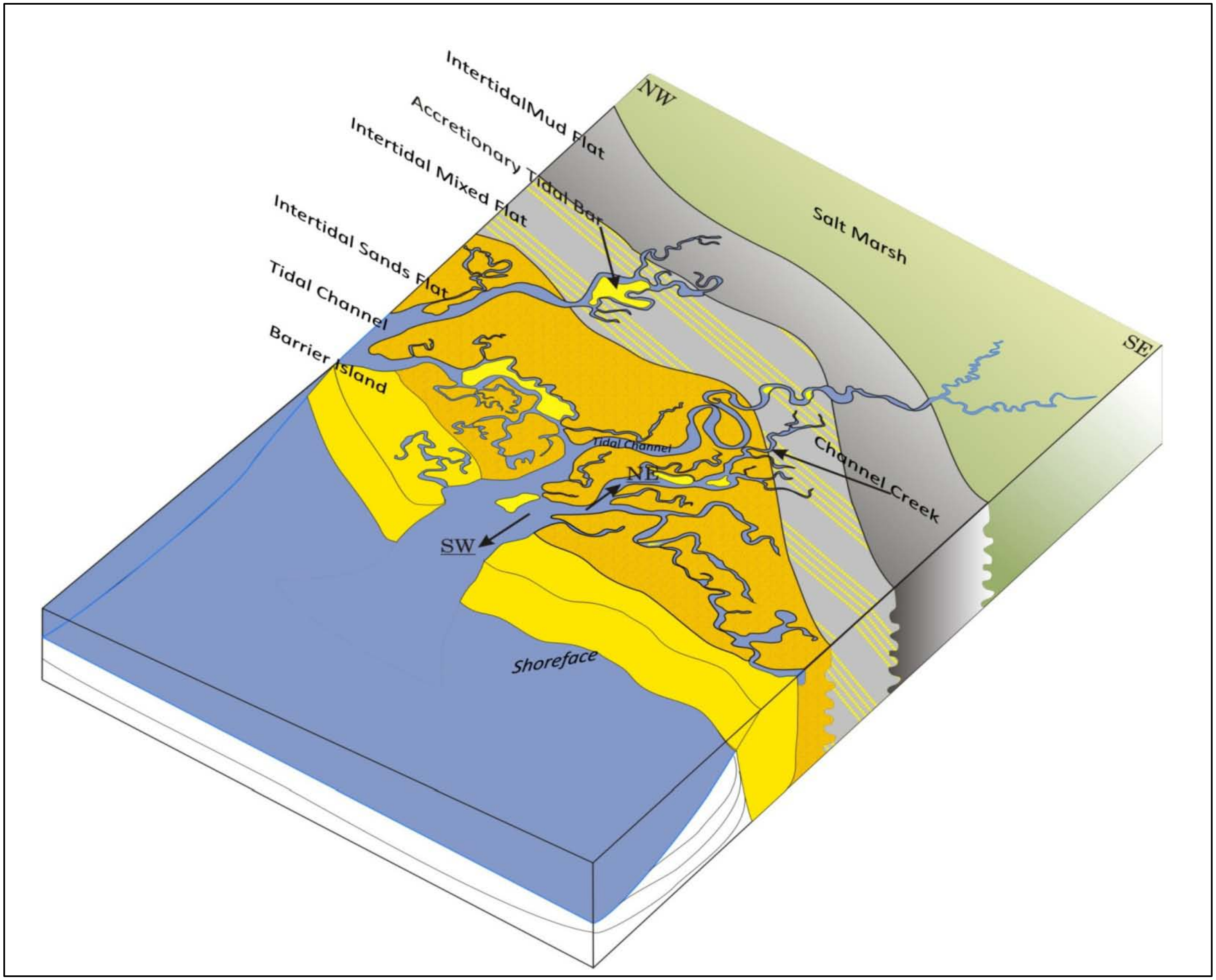

Figure 6. Tidally influenced depositional facies model of the cored segment of the Umir Formation in the Colon-2 Well.

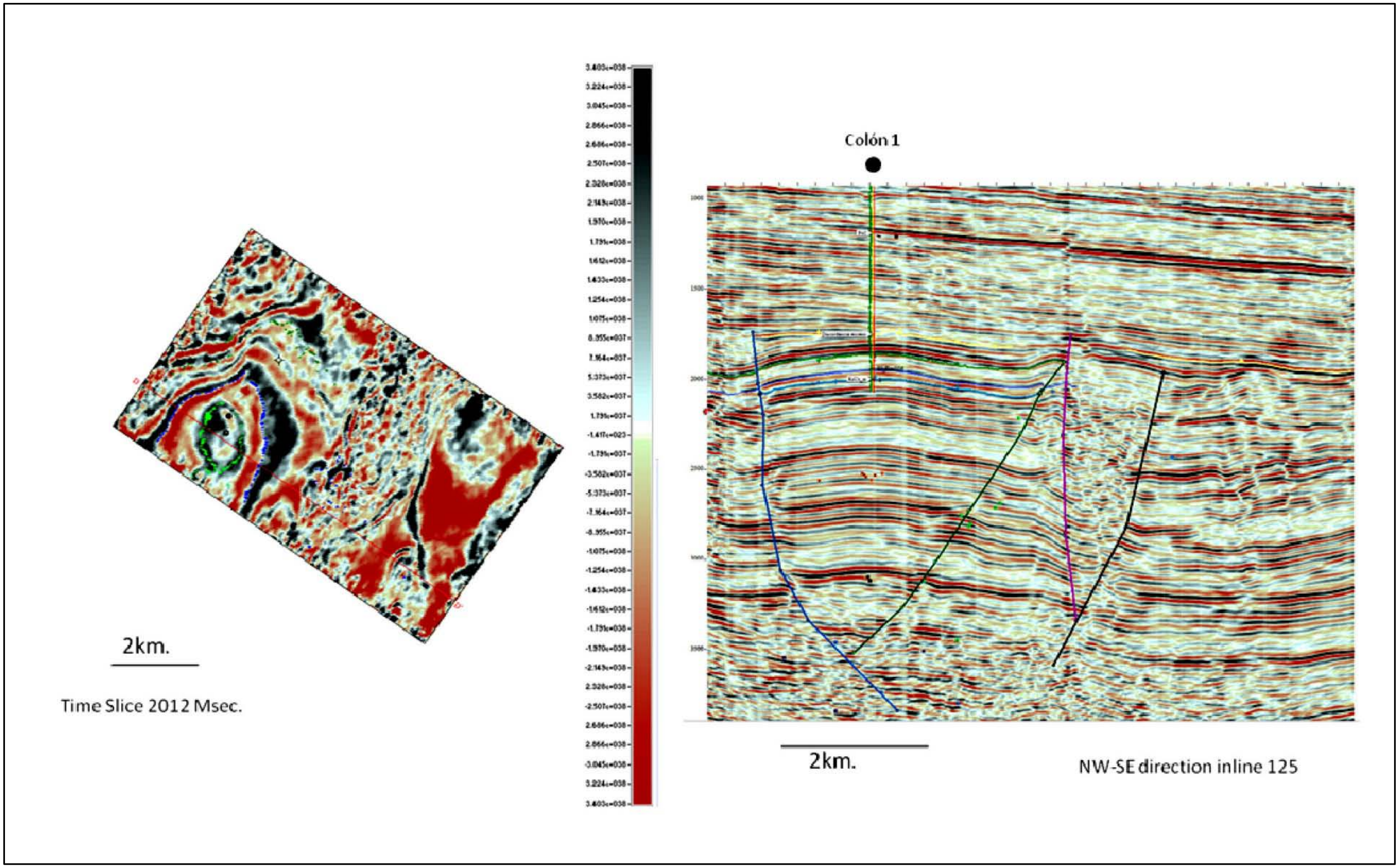

Figure 7. Seismic expression of Colon Oil Field. The left image is a time slice showing the four-dip closure with the Umir Sand Horizon in green. The right image shows the “pop up” anticline that forms the trap with the producing zone in blue.