

Oil Distribution in the Carbonera Formation, Arenas Basales Unit. A Case Study in the Quifa and Rubiales Fields, Eastern Llanos Basin, Colombia*

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Abstract

The Eastern Llanos Basin has almost 70% of the reserves in Colombia and the Rubiales and Quifa fields are the largest heavy oil fields found in this basin showing a production of almost 250,000 stbbl/day in November, 2012. Continuous drilling activity has resulted in significantly increased production, but it has demonstrated that there are some stratigraphic issues that are affecting the oil distribution and, consequently, the drilling success in both fields.

The main oil accumulation in the area occurs in the Carbonera Basal interval or "C-7" unit of Carbonera Formation, informally known in the area as "Arenas Basales;" it has been deposited in a varied succession of fluvial environment genetic units, which hold oil-producing columns between 7 and 60 feet thick. In the Rubiales and Quifa fields, the main trapping mechanism is a combination of structural and stratigraphic features. The proper structural traps are formed by normal faults upthrown to the basin. The stratigraphic features comprise diverse fluvial regimes in which channel bars are stacked vertically as parts of successive fluvial plains, which in turn vary laterally. Using 2D seismic information and well data, it has been possible to identify two major seismo-stratigraphic units that represent the oil reservoirs. The "Arenas Basales," identified in the northern part of the Quifa Block, is lithostratigraphically equivalent to the "Arenas Basales" in Quifa Southwest and Rubiales fields, but chronostratigraphically it corresponds to an older genetic unit. The presence of more than one oil-water contact in some wells confirms the existence of different reservoir flow units in these fields.

Changes in lateral continuity of facies can be correlated showing muddy facies at one side and sandy facies on the other side, all of this to the scale of the sub-areas in Quifa Block. The implementation of 3D seismic inversion in a recently acquired seismic volume may help to identify facies changes and oil distribution in the "Arenas Basales", increasing the drilling success in the Rubiales and Quifa fields.

Introduction

The Eastern Llanos Basin in Colombia has almost 70% of the reserves in the Country. Mackenzie, 2012 (in Pantin, 2012) reports 1,869,200 Kbl for the basin. Although the Eastern Llanos Basin has been drilled extensively, many issues are still not well understood. Rubiales and

Quifa are two of the largest fields of the basin. They are located 300 km southeast of Bogota City ([Figure 1](#)). The combined production of these two fields is almost 250.000 barrels per day as of November, 2012. The oil produced is 13 degrees API. Based on results from more than 600 wells, reservoir complexity and lack of continuity of the reservoirs have been demonstrated.

The basin has been divided into four domains characterized by their structural styles, deformation ages, and stratigraphy (Cediel et. al., 2011). Rubiales and Quifa blocks are located in the Vichada Domain which is part of the flat foreland. [Figure 2](#) (modified from Gomez, et al., 2009) shows a regional section in the Vichada Domain with the structural pattern encountered. This domain is characterized by a thin sedimentary section onlapping the basement, normal faults, and drape structures. The structure can be described as a northwest dipping homocline with a cover of Cenozoic to Recent sediments. This homocline is slightly deformed by synthetic or antithetic normal faults of small displacement.

[Figure 3](#) shows the stratigraphic column for the fields. Paleogene and Neogene sediments overlie a Paleozoic sequence. Diachronic erosion or time-transgressive deposition of Upper Cretaceous to Paleogene sequences produces a basal, onlapping stratigraphic architecture (to the east-southeastward) (Yoris, 2009). At the Rubiales and Quifa blocks areas, this basal onlapping sections rests directly on a Paleozoic sequence. It corresponds to the basal section of Carbonera Formation. The Carbonera Formation (Gomez et al., 2009) includes a succession of sandstones and shales. These shales represent the vertical seal to the hydrocarbon migration. Younger units of this Paleogene sequence are known in the area as “Arenas Basales,” which is an informal unit used to describe the Carbonera Basal Interval or “C-7,” an oil-bearing stratigraphic interval in Rubiales and Quifa blocks. This unit is part of the basal onlapping section deposited in diverse fluvial regimes in which channel bars are stacked vertically in successive, laterally variable fluvial-plain deposits.

Overlying Carbonera Formation is the Leon Formation deposited during a period of marine transgression. The main lithology in this formation is shale. The Guayabo and Necesidad formations, deposited subsequently, correspond to shallow-marine and continental sediments, respectively.

Overall, the structure in the basal sands can be described as normal-faulted, homoclinal section, dipping slightly to the northwest. It has been determined that these normal faults control the distribution of the reservoirs in the area and explain the presence of different compartments for the accumulation of hydrocarbons, especially at the north end of the Quifa block. Additionally, lateral variations of facies play a key role in the trapping mechanism of hydrocarbons. Therefore, we think that the trap in the area is a combination of structural and stratigraphic features.

Identifying one of the components in the stratigraphic complexity is the main focus of this study. Evidence supports the necessity of using chronostratigraphic criteria to develop the area.

Results and Discussion

In the past, stratigraphic unit correlation has been performed using lithostratigraphic criteria. This type of correlation leads to problems in identifying correctly the producing units. Despite the stratigraphic complexity, a single well top has been used to name the top of the oil producing unit.

In Rubiales and Quifa fields, hundreds of wells have been drilled; some have seismic calibration. Using this calibration, it was possible to identify that the oil in Arenas Basales is related to more than a single stratigraphic unit. This chronostratigraphic criterion has allowed us to identify underexplored areas that have not been well drained.

[Figure 4](#) shows a NW-SE composite seismic line with some wells from Rubiales and Quifa Fields. The seismic line is flattened to a maximum flooding surface near to the top of “Arenas Basales”. The gamma ray log, also plotted on the section, shows the sand intervals (filled in black). Oil intervals are highlighted at each well. From north to south we have identified two major seismo-stratigraphic units that contain the oil reservoirs. The “Arenas Basales,” identified at the northern part of the Quifa Block, is lithostratigraphically equivalent to the “Arenas Basales” in Quifa Southwest and Rubiales fields, but chronostratigraphically, it corresponds to an older genetic unit. Other seismic intervals underlying the oil prone intervals are also identified. They correspond to older units. These units are water-prone in the areas of Rubiales and Quifa fields. The presence of water in some wells could be interpreted as a result of the structural position within the homocline.

In the area, from bottom to top, “Arenas Basales” interval can be subdivided in three major units. The lower brine-saturated unit is characterized by onlapping transgressive sandstones. The middle unit is onlapping the basement paleohighs, whereas the upper unit is deposited in the entire area of Rubiales and Quifa. This upper unit changes facies in an approximate north-south trend. At the eastern part of the section, it is shown that the Carbonera Fomation is onlapping a Paleozoic sequence. [Figure 5](#) shows a facies model of the previous section. This figure also shows the facies changes along chronostratigraphical units. Sand-to-shale ratio increases toward the southern part of the basin. To the north of Rubiales and Quifa fields, the middle unit underlies an upper shale unit. Oil accumulations can be found where both, structural highs and sandy facies, are encountered. In the areas of Quifa Southwest and Rubiales, the two uppermost units have sandy facies, and the vertical seal is absent between the upper and the middle units. Therefore, the oil has migrated to the uppermost unit in these areas. The presence of different stratigraphic compartments could control the oil accumulation.

[Figure 6](#) is of well log from Rubiales Field, where it is possible to identify two different oil-water contacts in the interval lithostratigraphically named “Arenas Basales.” The presence of more than one oil-water contact in some of the wells confirms the existence of different reservoir flow units.

The development of these fields has been accomplished by drilling horizontal wells, which targeted the uppermost unit. The middle unit could not be drained as well as the upper unit, and therefore, it is possible to increase the recovery factor of the fields. The presence of more than a single oil-prone unit implies complexity in the development plan of these fields.

The use of seismic elastic inversion has allowed the volume estimate of clay content in the “Arenas Basales” complex. This technique allows us to identify undeveloped compartments increasing the future potential of the area. Also, it is a useful tool for predicting barriers because in this kind of reservoirs, differences in clay content could control oil migration and trapping.

Conclusions

The chronostratigraphic interpretation of the area has permitted the identification of multiple intervals that can be oil-prone in the Rubiales and Quifa blocks. The interpretation of these zones using seismic inversion helps in identifying bypassed areas and developing an optimized production plan for each oil-bearing zone.

References

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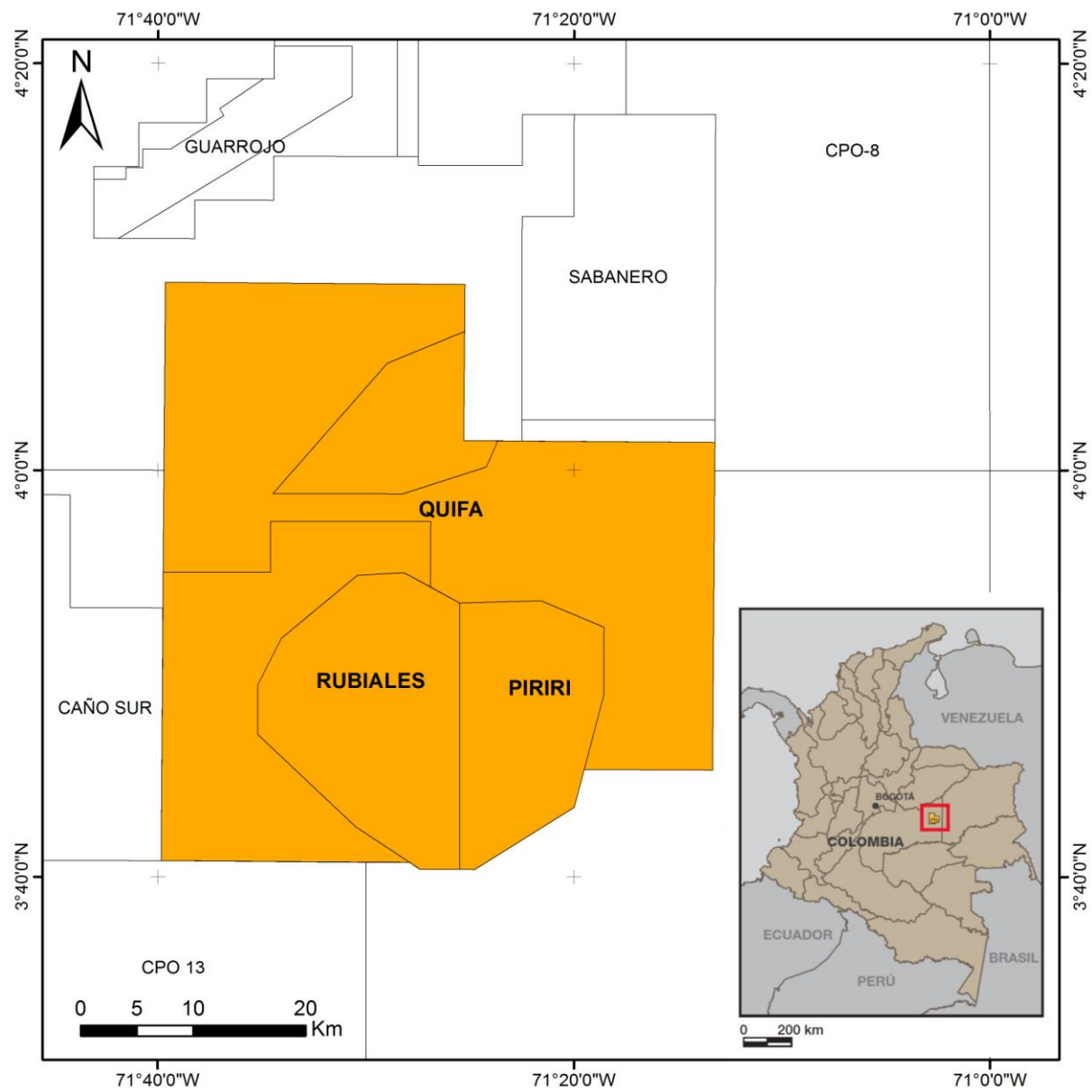


Figure 1. Location map of Quifa and Rubiales blocks.

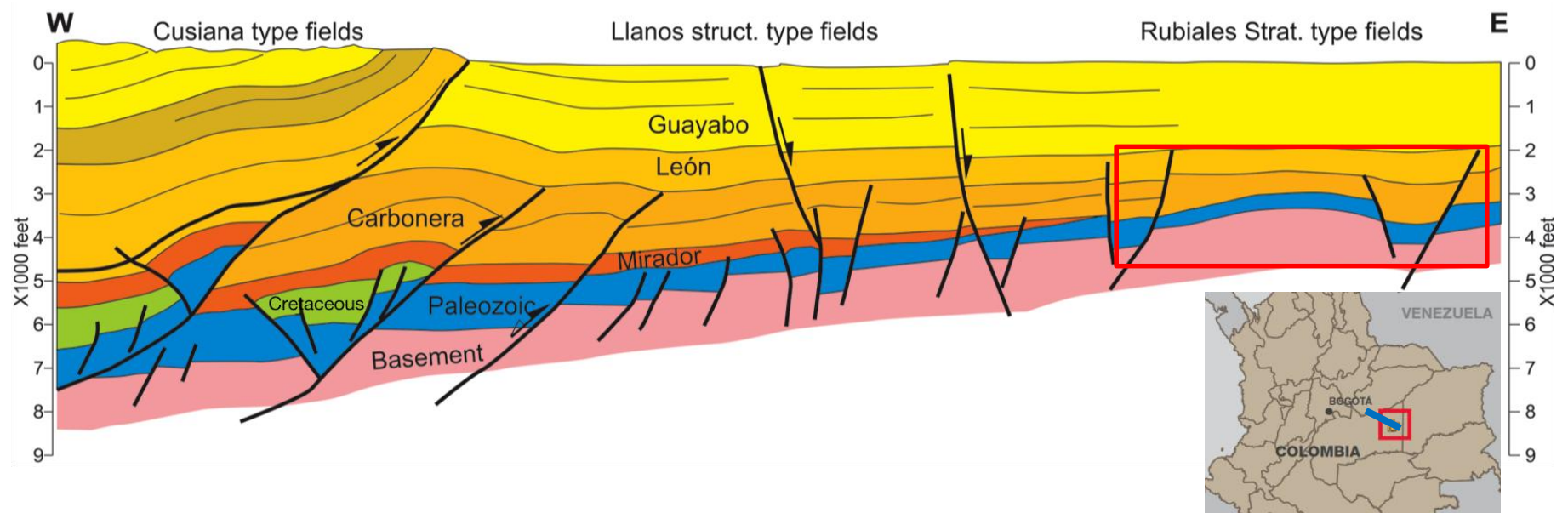


Figure 2. Structural section of Llanos Basin (modified from Gomez, et al., 2009).

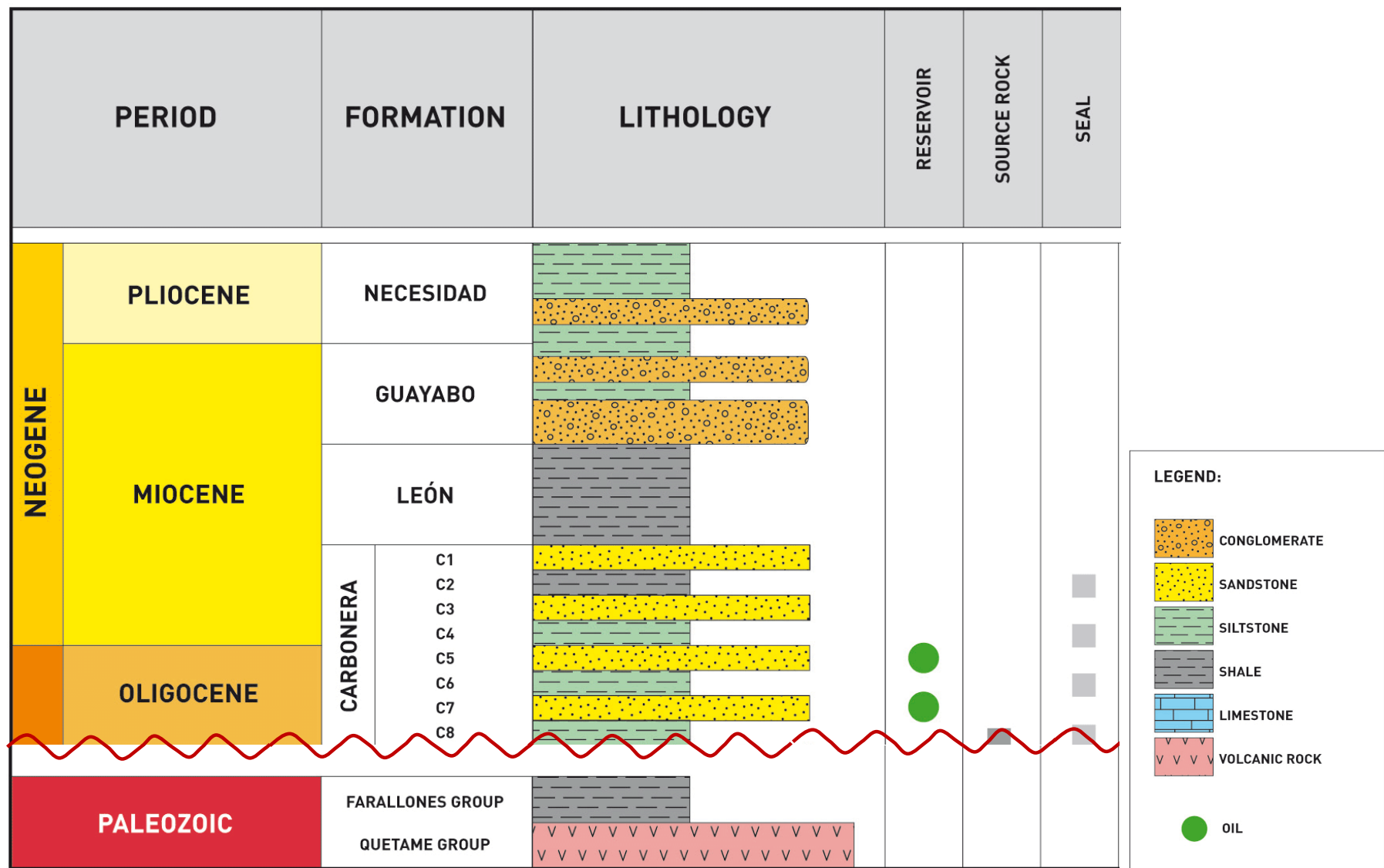


Figure 3. Stratigraphic column of Rubiales and Quifa blocks.

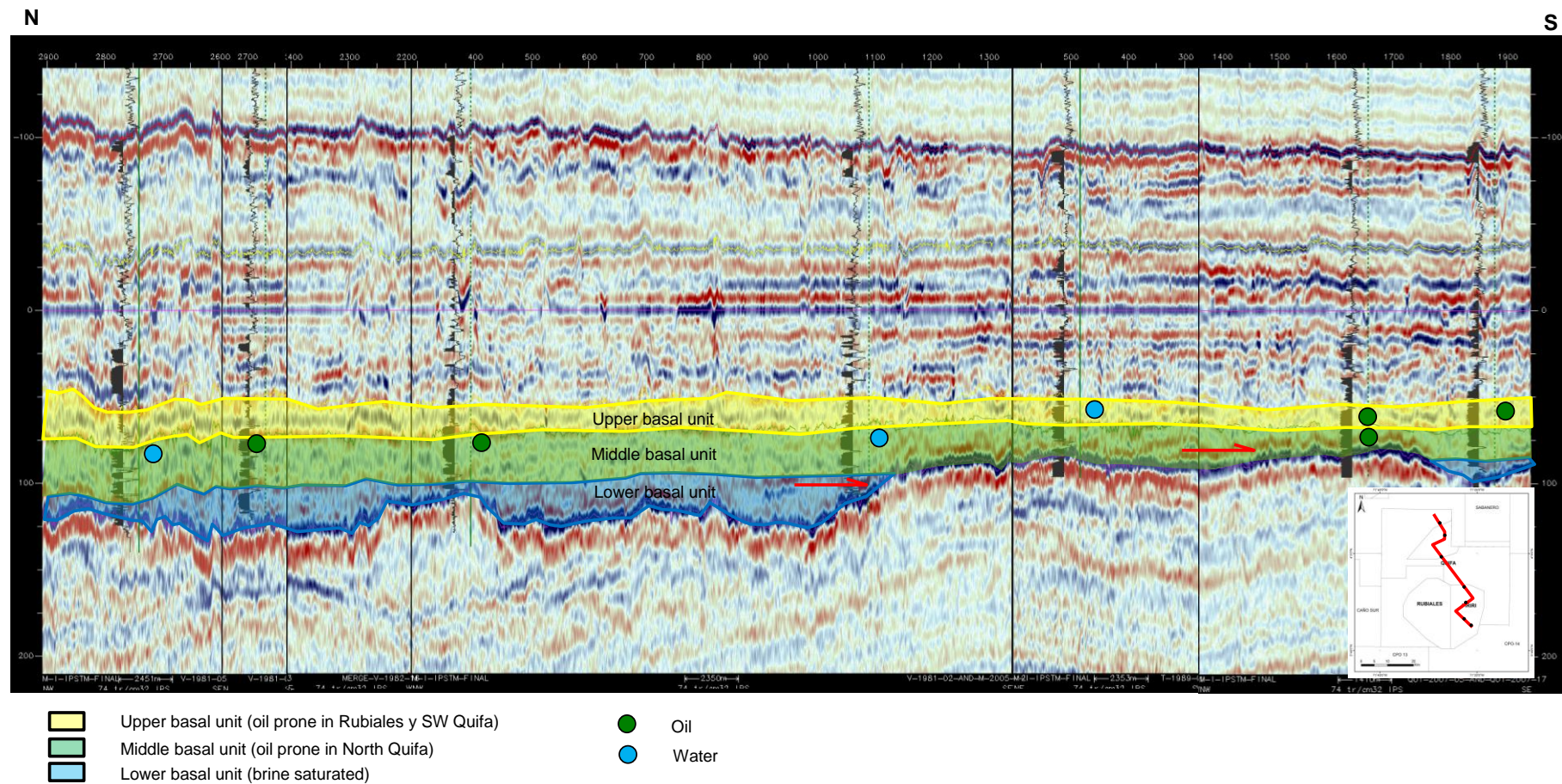


Figure 4. Interpreted stratigraphic composite seismic line.

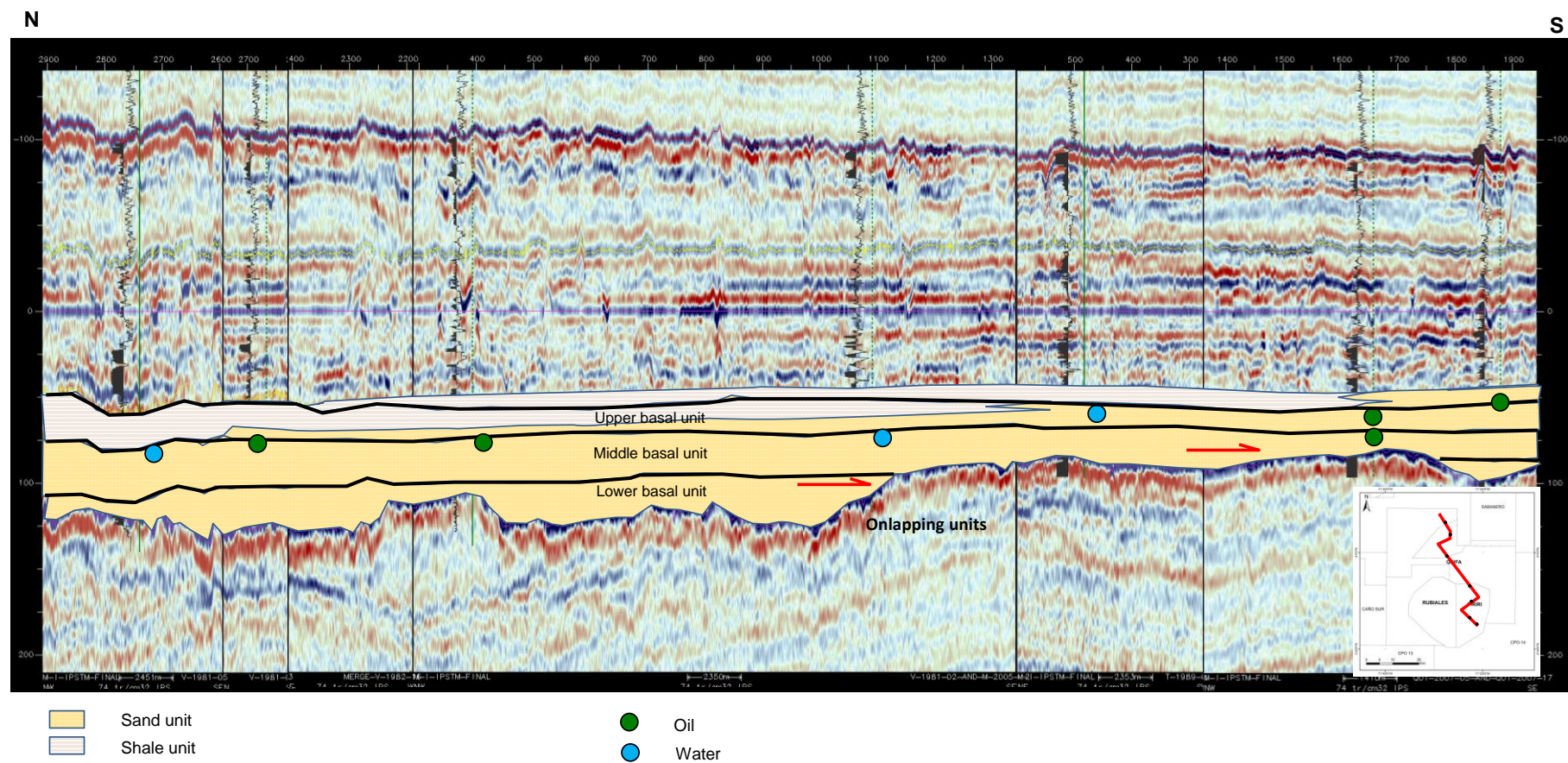


Figure 5. Facies model of basal units in Quifa and Rubiales blocks.

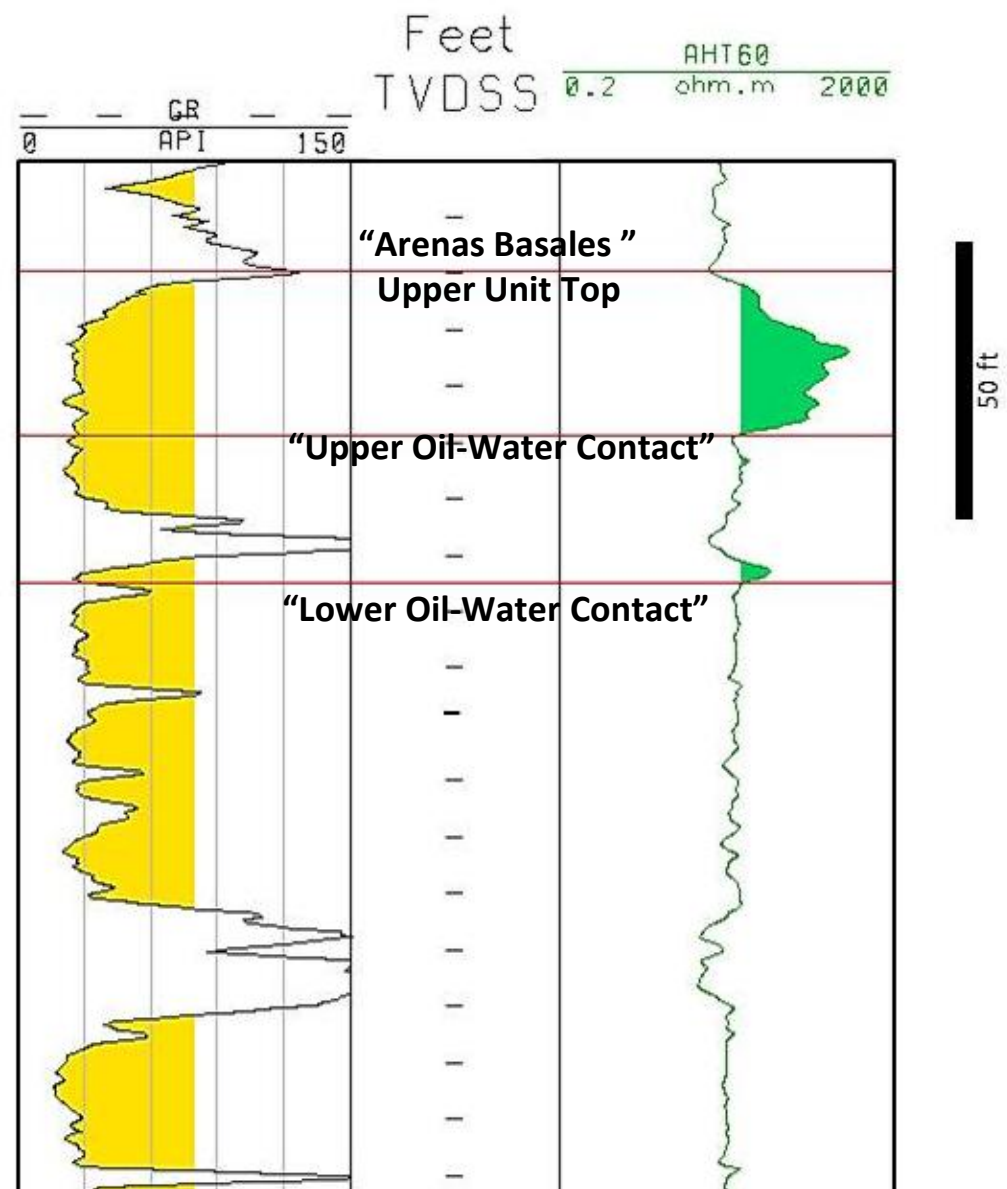


Figure 6. Well with a double oil-water contact.