

PS Application of Modern Reservoir Characterization Technology in Mature Fields to Increase Production*

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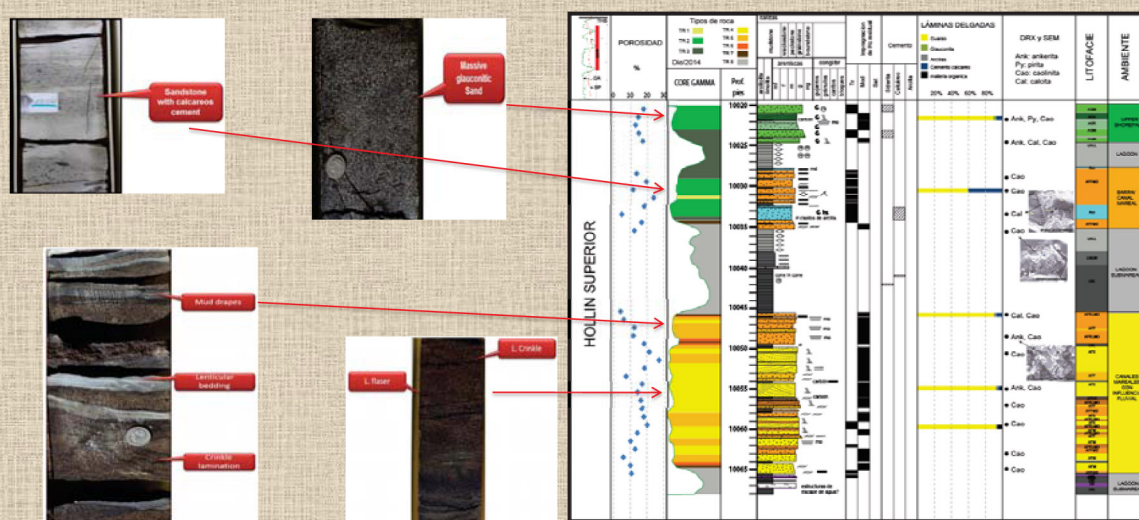
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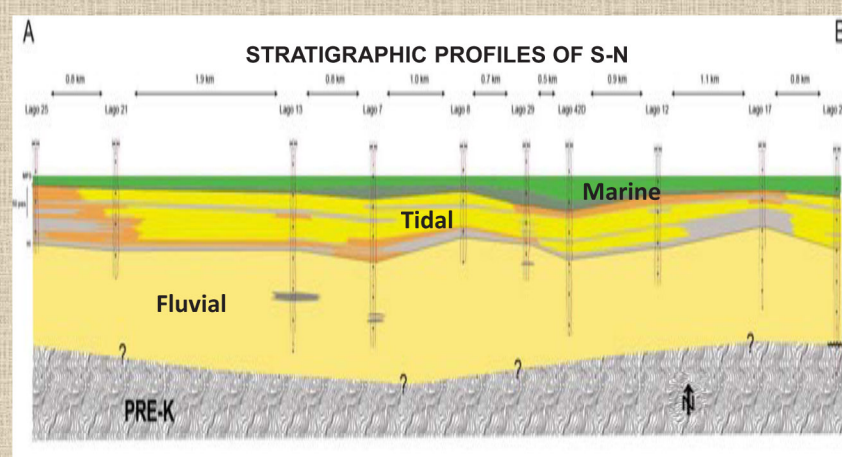
Abstract

This is a study and workflow that was applied to a mature field in Eastern basin of Ecuador, with the objective of increasing the reserves and production and recovery factors. To increase production in this mature field, modern techniques of characterization were implemented. Refining the calculation of the OOIP using static and dynamic models and understanding the key factors affecting production performance and fluid flow in the reservoir, it was possible to find more oil reserves in the reservoir, define potential drilling areas and design a new development plan of the field.

Sedimentological Model

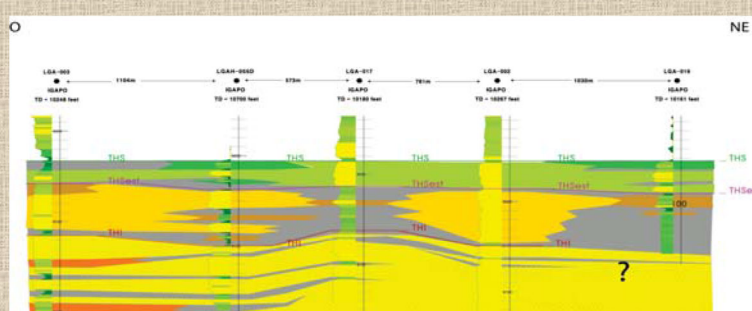


The sedimentological analysis was done from a combination of core data, log data, and detailed geology from the area. The sedimentological structures were key to re-define the different intervals for the Hollin. Before this study, the basin was divided into two sections (upper and lower Hollin reservoirs). After this study, we were able to define three environments.



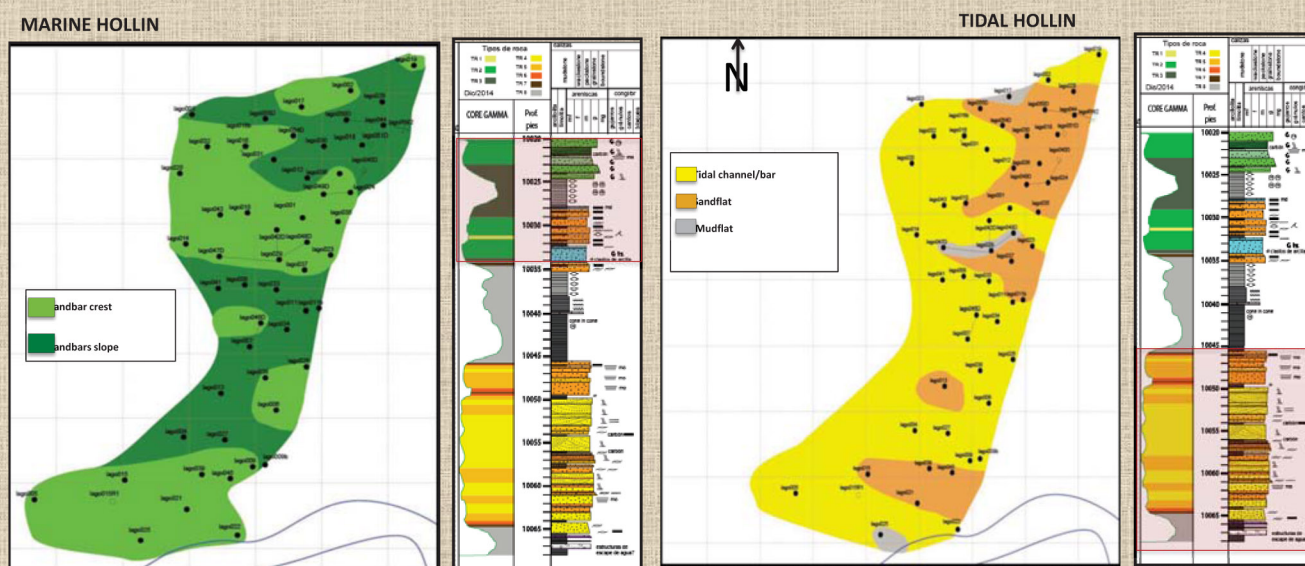
Geometry of the sand bodies - Section (North-South)
At the base is a continuous sandstone, with very few seals associated of a Fluvial Environment
Transitional zone - defined as tidal Environment with some continuous seals that limit the reservoir quality.
On Top is a Transgressive cycle - defined as Marine Hollin a very continuous reservoir

Fluvial section: continuous sandstones with sporadic, thin, shaly intervals
Tidal section: amalgamated channels and bars sandstone with continuous shaly seals
Marine section: continuous glauconitic sandstones



Perpendicular cross-section NE-SO

Environmental depositional maps



Sedimentological model average maps of the predominant environmental facies:

The main lithologies are glauconitic sandstones (fine- to mid-size grains) with thick layers of cross stratification. We defined two facies in the marine Hollin: sandbar crest (light green) and sandbar slope (dark green).

We defined three sub-facies in the tidal Hollin: channels/sand bars (yellow), sand flats (orange), and mud flat (grey).

Petrophysical Analysis and Modeling

SEM electronic microscope scan

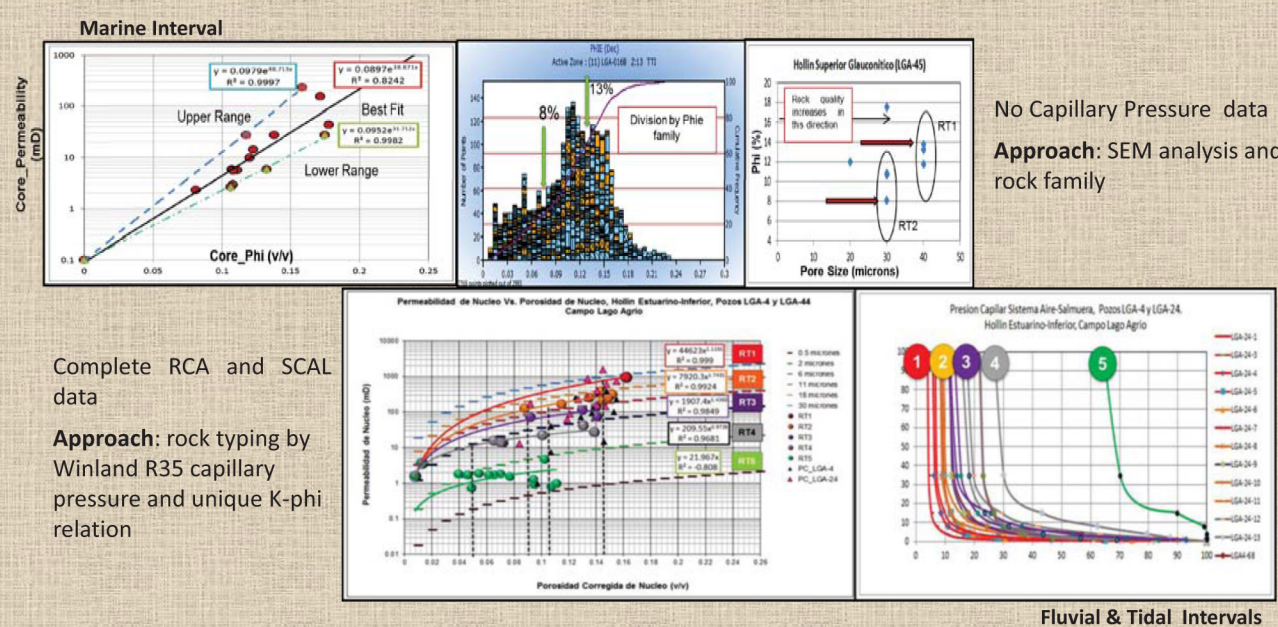


Marine Hollin
Formation damage owing to ferrous-calcareous cement. Highly compacted sandstone. Ankerite formation.

Towards the top in the marine Hollin there was high content of iron on some minerals like sideritic Cement. Also ankerite was identified, showing diagenetic damage in the formation. This lowers the porosity and the pore throat, and therefore the reservoir quality on the rock.

Tidal Hollin
Tangential grain contacts, sporadic kaolinitic matrix. Occasional calcareous cement.

The tidal Hollin has better grain arrangements. Low presence of kaolinitic matrix and occasional calcareous cement
For this reason the tidal Hollin has a better flow capacity than the marine Hollin



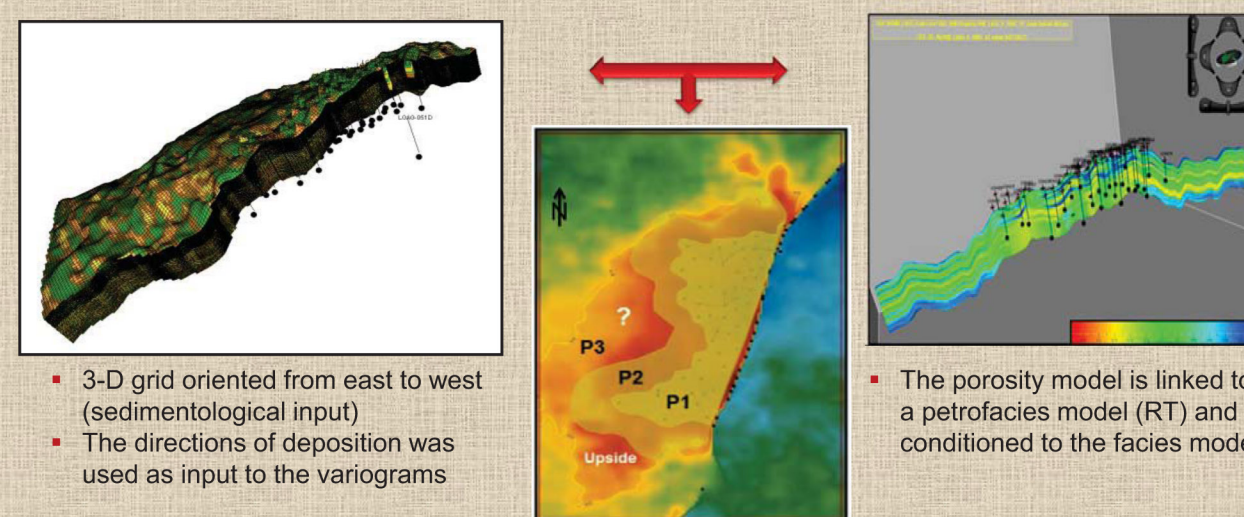
Complete RCA and SCAL data

Approach: rock typing by Winland R35 capillary pressure and unique K-phi relation

No Capillary Pressure data
Approach: SEM analysis and rock family

We did a petrophysical study with the goal of generating the rock types used on the static model. A different approach was used for the different reservoirs due to the available data. For the marine interval, there was no capillary pressure available, so we analyzed the effective porosity and the pore diameter from the electronic scan images. One seal and two reservoir rock types were defined. For the fluvial and tidal Hollin, there was Capillary pressure available. We integrated this data with a Winland plot and five rock types were identified for each interval; one considered seal and four considered reservoirs. The resulting rock types defined in this analysis were used to populate the petrophysical properties in the static model.

Static Model

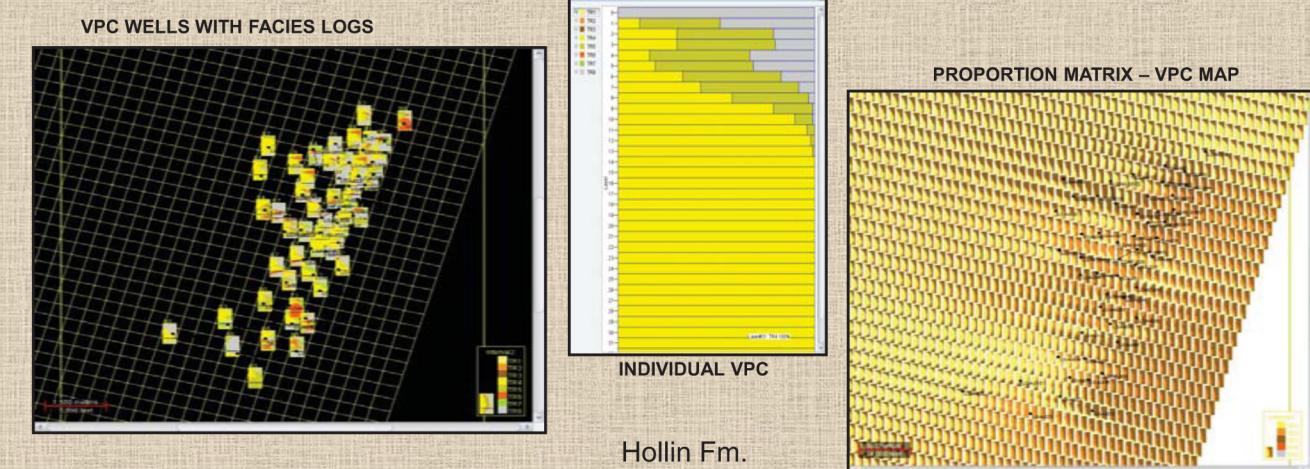


The goal of the geocellular model was the volumetric calculation and the dynamic simulation. The grid was oriented along the main direction of sedimentation, based on the paleo-current analysis. The rock type was tied to the petrophysical model, so each rock type has a porosity range. The porosity model was conditioned to the facies model. This allows a more predictive model. The STOIP calculation was done for P1, P2, P3 case scenarios. There was an increment in the area of the reservoir as defined in the most recent seismic interpretation. This interpretation combined the available 2D and 3D seismic in the area. The 3D was not available before in previous models
P1 = 500 m, proven reserves (official STOIP)
P2 = 2 km, likely reserves
P3 = Possible reserves. Calculated using the OWC and the structural spill point

Static Model

Facies Modeling

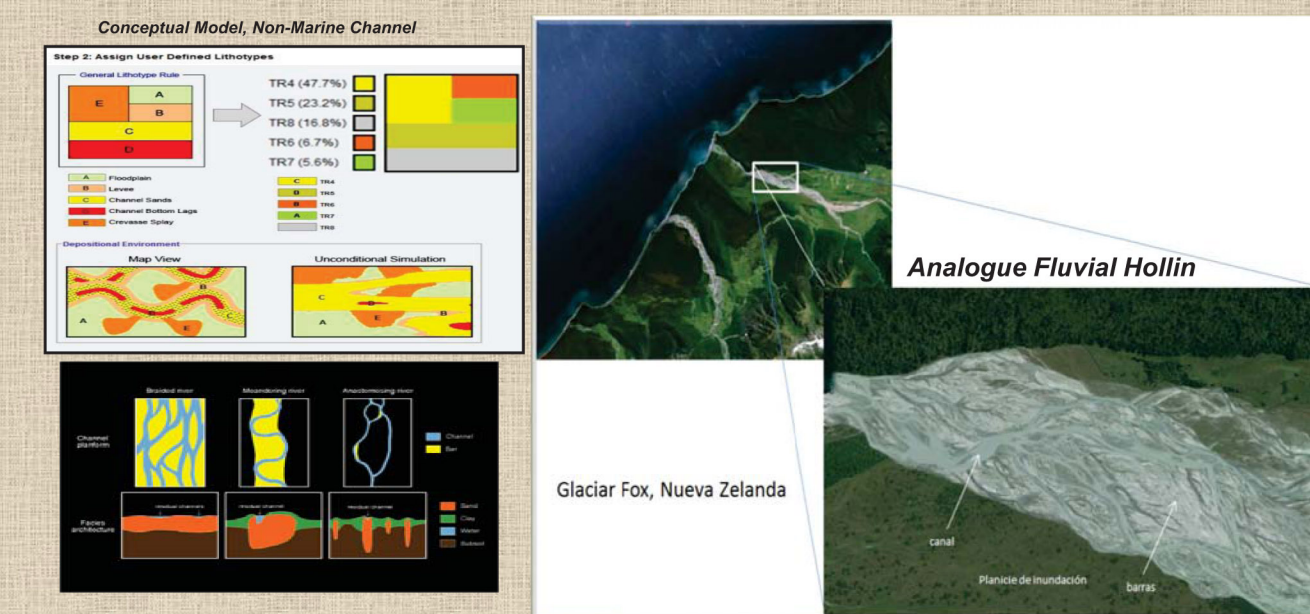
RTs + VPM + Variograms + Depositional Environment



Hollin Fm.

When creating the facies 3D model a VPC is created for each well with facies interpreted. The multiple VPC curves are interpolated into a vertical proportion matrix. This matrix is used later as volume trend (Facies probability Volume) in the facies simulation in combination with the Variograms.

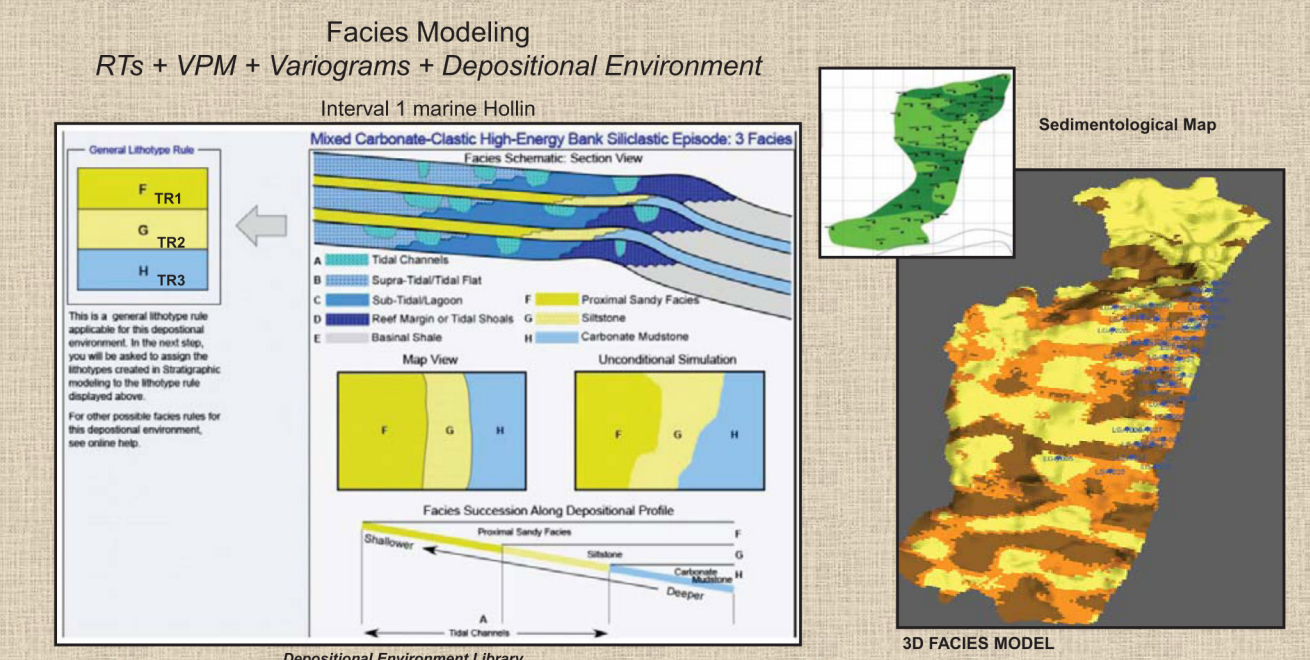
Stratigraphic - Sedimentological model, Hollin Fm



During the study, we looked for analogue depositional environments. In the DSG platform, it is possible to select from an internal library of depositional environments that will guide the variogram and the model to create more realistic models. We followed this workflow for every reservoir in the model.

This workflow was followed for every reservoir on the model.

3D Geocellular Model, Hollin Fm.



Final model for the Marine Hollin Interval

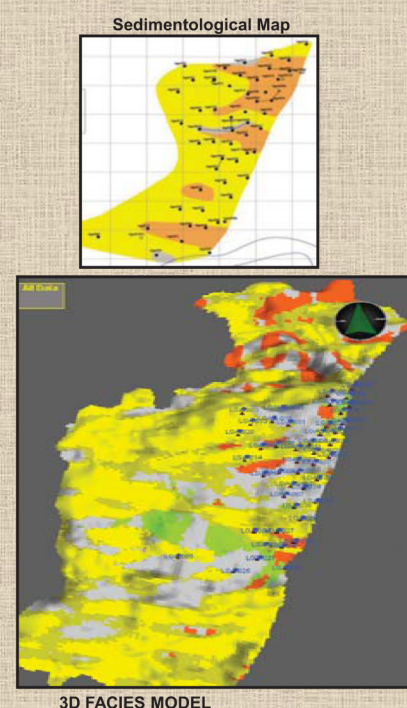
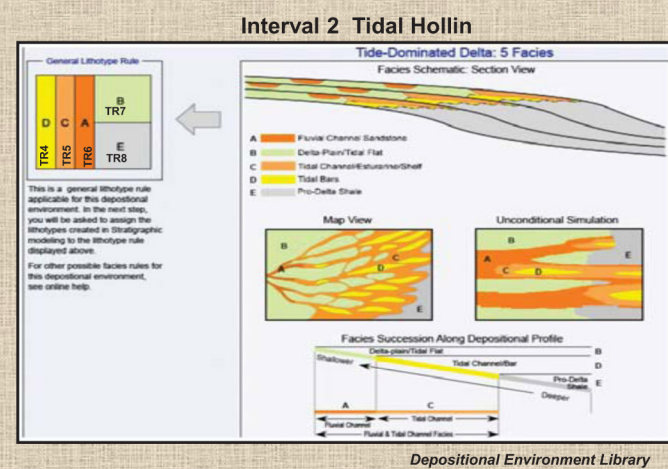
In a depositional environment library (available in DSG software), we can define the existing relationships between the facies, transitions, and truncations. We used the facies model for every interval, combining the sedimentological maps from the sedimentological studies, the vertical proportion maps, and the library of depositional environments. We also used the variograms analysis to define the extension, width and direction of the different lithologies.

Static Model

Hollin Fm.

Facies Modeling

RTs + VPM + Variograms + Depositional Environment



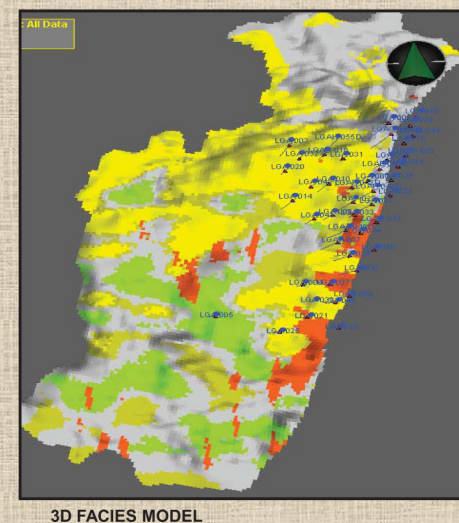
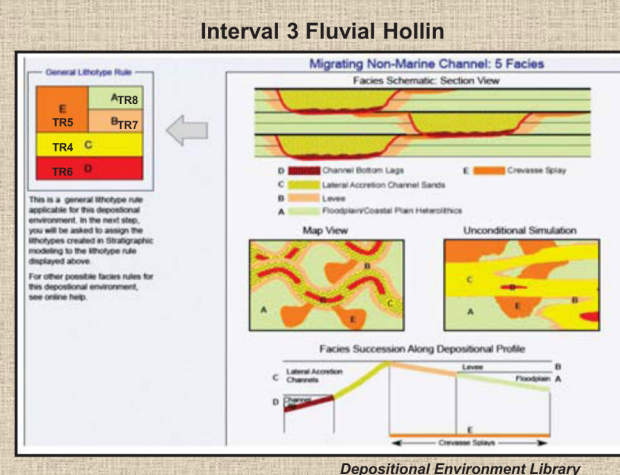
Tidal Hollin model

The same method was used for each unit in the reservoir, Defining every depositional environment and characteristics for each reservoir
Combining the sedimentological maps, depositional library and the variogram analysis

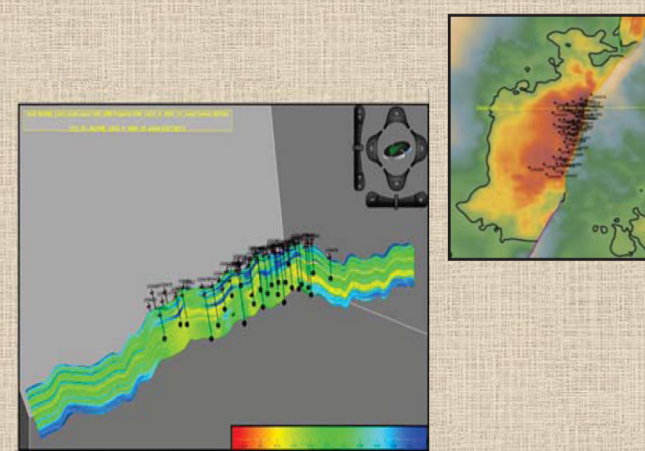
Hollin Fm.

Facies Modeling

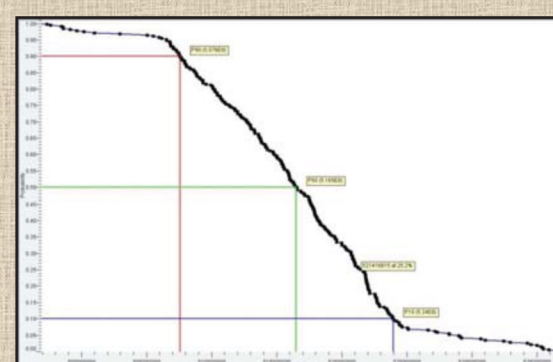
RTs + VPM + Variograms + Depositional Environment



The resulting map for the Fluvial Hollin the same steps were followed



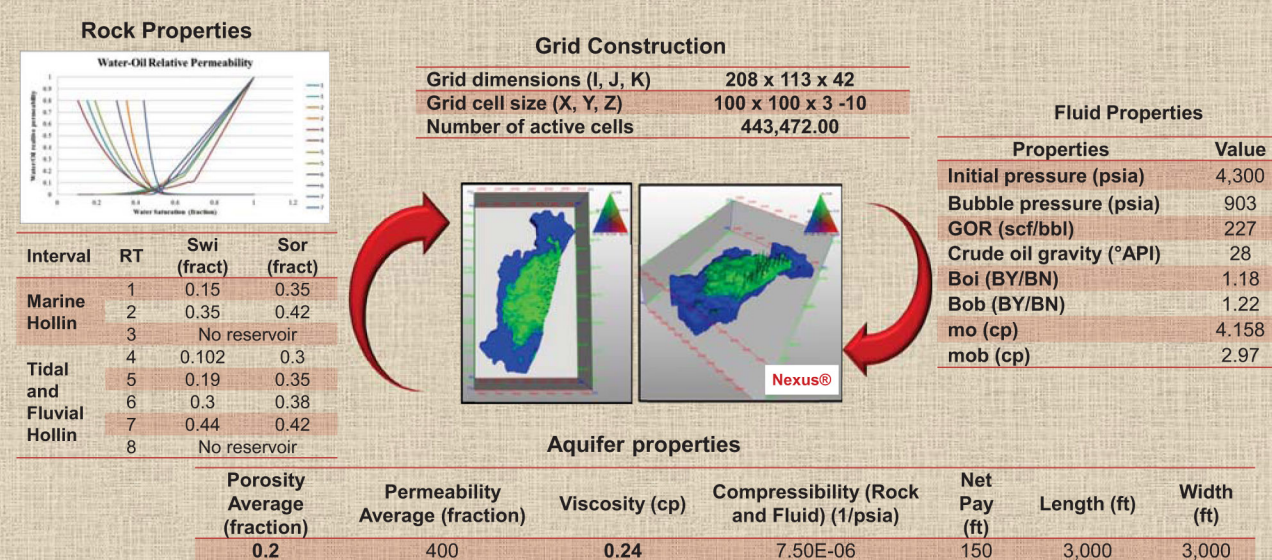
Petrophysical model



Uncertainty model

After running multiple realizations of the facies models. Multiple realizations for petrophysical distributions of the RT from the petrophysical analysis (conditioned to the facies). The volumetrics calculation and the uncertainty were calculated from the multiple realizations.

Reservoir and Dynamic Model

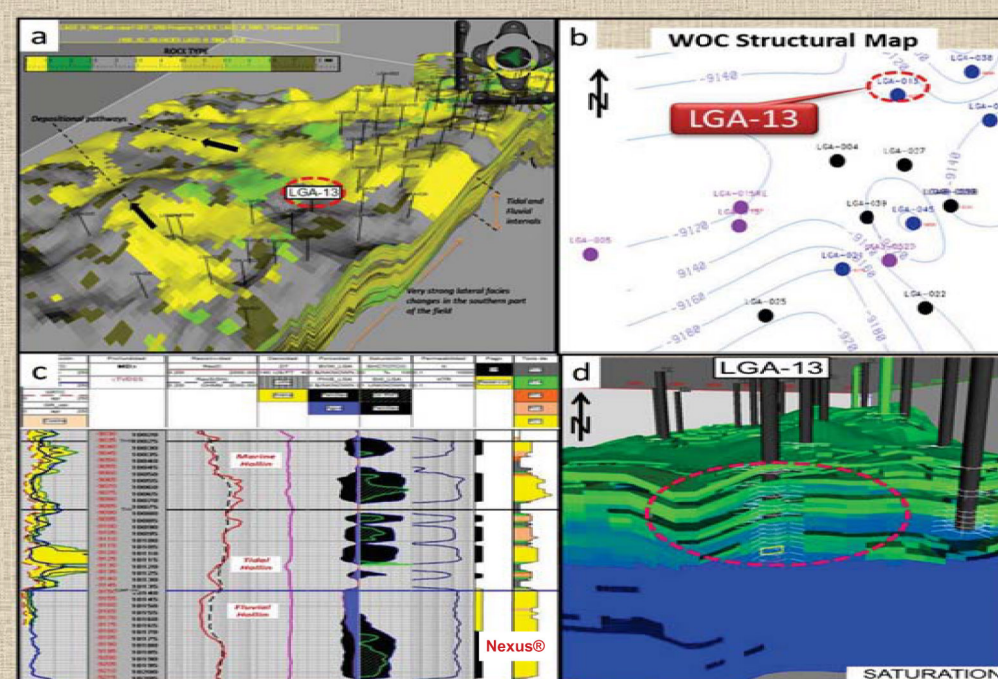


We scaled the simulation grid at a 2:1 ratio in the vertical direction to reduce the simulation time. The properties of the fluid come from validated PVT analysis (the main properties are in the table above). To calibrate the pressure in the reservoir produced by the bottom water drive, it was necessary to incorporate a Carter and Tracy aquifer with the properties. We created relative permeability curves based on the petrophysical analysis. End points were defined for the three marine and five fluvial tidal intervals.

Water-Oil Contacts differences: 9160-9200

North: No compartmentalization or potential barriers

South: Changes in reservoir behavior. Had stratigraphic component.

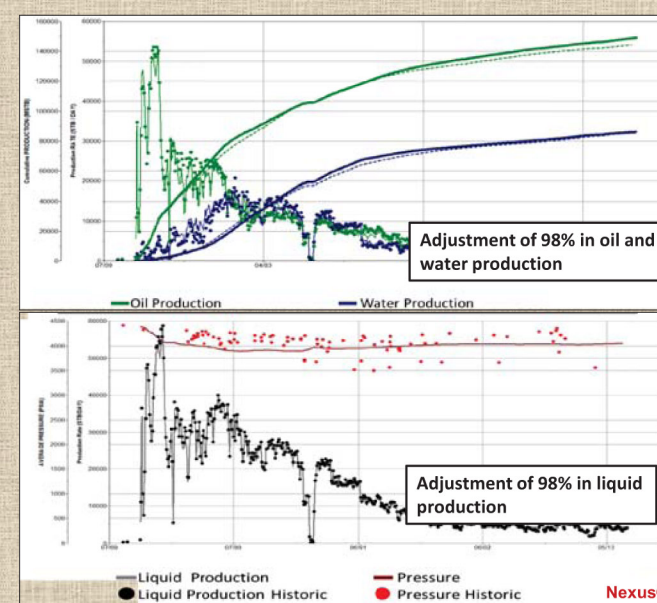


In the analysis of original fluid levels, differences in WOC were found with variations between 9160-9200, and two trends were observed.

- In the north, there were no compartmentalization or potential barriers to justify these changes.
- In the South, there were changes in the behavior of the reservoir and an important stratigraphic component. Limiting the continuity of sand bodies.
- In the LGA-13 well a saturation log was taken recently. In image A, a lateral variation of facies around the wells is shown; in image B we see a variation of WOC around 40-60 feet. Image C, the saturation log shows bypass oil in the different intervals which matches with the simulation model; and also strong-stratigraphic component of the well

The primary changes included:

- Sensitivity of WOC
- Adjusted aquifer properties
- Vertical barriers and seals
- Adjustment with Corey correlation exponents
- Sensitivity vertical permeability between 0.1-0.2
- Matching between workovers and production history



Adjustments to obtain a historic matching

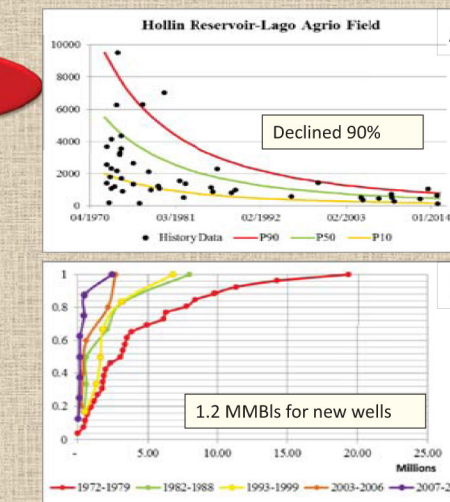
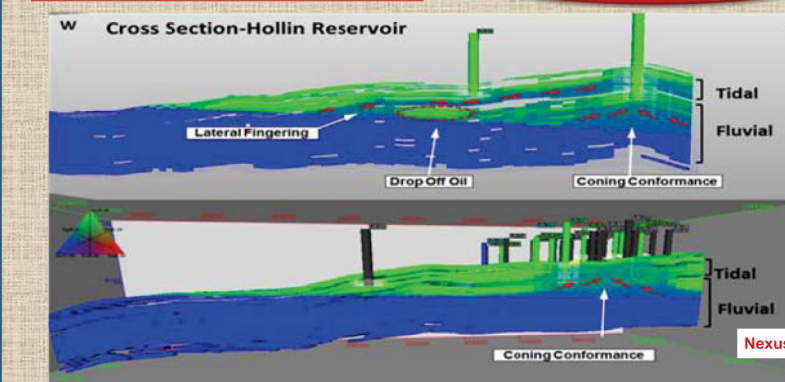
- Sensitivity to OWC.
- Adjustment of the properties of the aquifer.
- Sensitivity to the Corey exponents in permeability relative to water.
- Sensitivity to vertical permeability between 0.1 and 0.2.
- Seals or barriers were identified by the geological interpretation.
- Match between WORKOVER and production history. An adjustment of oil and water production of 98% is shown, also the same adjustment for the liquid production. This adjustment was successful obtained because of the initial separation in Hollin formation between three intervals: fluvial, tidal and marine.
- This model is capable of representing fluid movement and water breakthrough in wells.

Reservoir and Dynamic Model

Current recovery-factor estimation

Interval	Recovery Factor (%)
Marine Hollin	2
Tidal Hollin	32
Fluvial Hollin	17
Total Average	17

Recognizing the Volumetric Potential

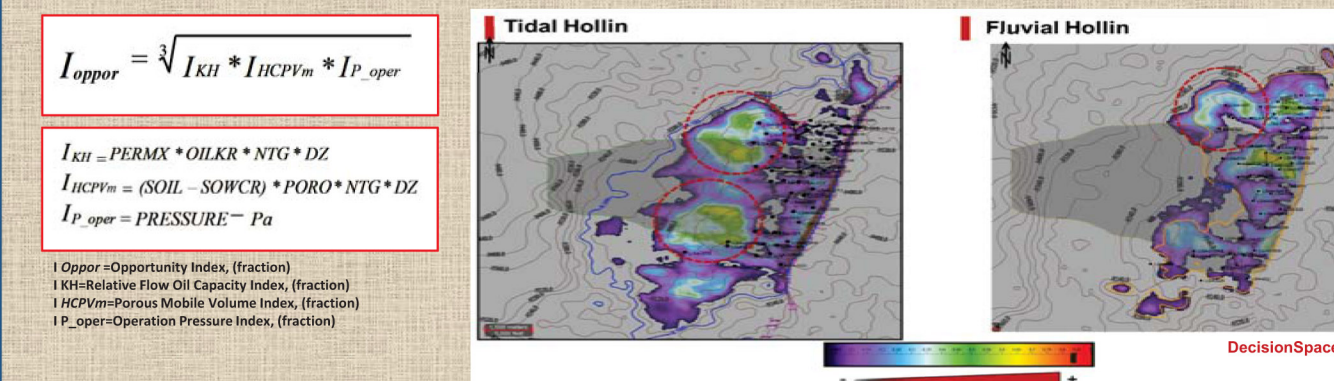


We estimated the recovery factor by intervals using original oil in place values; a low of 17% was obtained. We this reservoir has bottom water drive. There is an opportunity to increase production by contacting reserves by drilling wells. Other opportunities were identified using the dynamic model of 3D Nexus View. Two different areas were identified: a lateral fingering, where water is channeled through preferential areas leaving by-pass zones or not contacted oil. Also, the formation of coning that occurs in areas of good vertical transmissibility. Once the targets were identified there was an opportunity to optimize production and contact these reserves. Additionally, a vintage analysis was done.

Image A shows the analysis of the initial rates, which helped up to conclude that both, liquid and oil rates declined 90%, due to fine migration, which reduces well productivity.

Image B shows that wells were gathered by drilling campaign and 1.2 MMBbl for new wells is expected according the last campaign purple color.

Opportunity Index Map



In this study, we used a new methodology of opportunity index maps, that were key to identify potential drilling areas. We used previous net sand, bubble oil and water-cut maps to plan well locations. These maps gather static and dynamic variables and were created for the tidal and fluvial intervals by Earth Modeling and Nexus. White and green colors indicate the best rock properties and high saturation of moveable oil. Comparing the two Hollin maps above, we can see that the main target is tidal, displaying more potential with two potential areas: one north and one south. This is considered the sweet spot and defines a new development plan for this field. In the fluvial interval, there is low expectation because of early breakthrough of water.

Conclusions of Study

- The Hollin formation has 3 environments, fluvial, tidal and marine. The most prospective reservoirs are the fluvial and tidal intervals.
- The existing diagenesis differential between the Marine Hollin and the fluvial and Tidal Hollin intervals, affect the textural characteristics of the rock and the flow-storage capacity ratio.
- There are 3 types of rocks for marine Hollin, and 5 for the tidal and fluvial Hollin
- The total recovery factor was 17%, but could be improved using new technology and applying a new exploitation plan to more than 25%. With the design of new development plan

The synergy of a correct interpretation of the field using an innovative reservoir characterization met the expectations and provided new opportunities to increase production in a mature field.