Unlocking Reserves from a Secondary Reservoir in a Mature Field Through Integration and Engineering Approach: A Case Study from Oriente Basin, M-2 Reservoir, Eden-Yuturi Oilfield, Ecuador*

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Abstract

This presentation will offer an analysis of the results of several different completion techniques applied to a secondary reservoir in a mature field. These analyses allowed for the selection of the most effective solution for the development of what had been considered a secondary reservoir, optimizing the oil potential of the reservoir and its associated reserves by providing a reduction in workover time and incremental production through the use of an integrated engineering approach. The re-evaluation of the oil potential of this secondary laminated reservoir and its proper development was achieved through selecting the right technology after 15 hydraulic fractures, 13 perforations with propellant, and 8 high density shot perforations. The input data includes the integration of a detailed geological description, petrophysical evaluation, and a reservoir characterization added to pre and post evaluations of the completion techniques supported by production results. Comparing the results as a function of the completion design and its reservoir characteristics helped to determine the right completion scheme for the reservoir in terms of productivity and economics. The integration of the inputs and outcomes of each completion system showed that hydraulic fracturing is the most suitable method to unlock the oil potential and reserves of M-2 reservoir due to the higher productivity it creates and the sustained oil rates seen over time. The technique showed up to a 100% increase in oil production with unaltered water cut levels, which indicates that the fracture has contacted and connected multiple laminated oil-bearing sands. The suggested technique is supported by an optimal correlation between reservoir characteristics, oil productivity, and constitutive laws. The fracturing process was continuously optimized until reaching the planned objectives for the reservoir. The new oil potential, added to the lower water cut of the reservoir, also helped to reduce bottlenecks at surface facilities, which are currently at limit conditions due to high water production from the main reservoirs. Finally, the optimization process resulted in savings at OPEX and CAPEX levels.
References Cited


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Anne Valdez, Esteban Alba, Diego Tapia, Jonny Lomas, Martha Castillo, Petroamazonas
Field overview

M-2 reservoir description

Development & optimization

Results & Value
Field overview

- Started Production: October 2002
- 131 active wells @ May-2017
- Current Production: 34,500 BOPD
- Cumulative Oil Production: 252 MM BLS

PRODUCCION TOTAL DE PETROLEO - EDEN YUTURI

- BOPD vs. Years from 2002 to 2017

Graph shows a peak production in 2004 followed by a decline in subsequent years.
Field overview


M-1 Reservoir, 6,900 ft
M-2 Reservoir, 7,000 ft
US Reservoir, 7,200 ft
UI Reservoir, 7,350 ft
T Reservoir, 7,500 ft
Project opportunity

Cummulative Oil Production per Reservoir

Date

Recovery Factor per Reservoir

M-1 20%
M-2 3%
US 40%
UI 21%
T 18%
M-2 RESERVOIR DESCRIPTION
M2 reservoir description
Diagenetic processes affecting reservoir quality

Presenter’s notes: Core description shows that diagenetic process has degraded M-2 Reservoir Quality by the presence of Calcite and Glauconite. We can see the difference in the core; Point B has a good reservoir quality by other hand the point A show the degradation of the M-2 reservoir.
Presenter’s notes: We have wide ranges in permeability with low range in porosity. It confirms the varied and layered reservoir quality.

From this point of view, it is necessary to improve productivity by increasing the flow capacity through fractures that allow a better connection between the pores and between layers of quartz sandstones. The best technique to interconnect thin layers is hydraulic fracturing.

- Wide ranges in permeability for a narrow porosity ranges.
- Diagenetic process (calcite and glauconite) have degraded the quality of reservoir bodies

High vertical heterogeneity and low connectivity

Cross Plot M-2 (Core Porosity vs Core Permeability)
TRIAXIAL COMPRESSIVE TEST RESULTS

<table>
<thead>
<tr>
<th>Company</th>
<th>Petroamazonas</th>
<th>Date</th>
<th>Jan. 2014</th>
</tr>
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<tbody>
<tr>
<td>Well Name</td>
<td>EDYG-170</td>
<td>Job No.</td>
<td>HOU-140005</td>
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<td>Field Name</td>
<td></td>
<td>Saturation Fluid</td>
<td>3% KCl</td>
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<tr>
<td>Location</td>
<td>Ecuador</td>
<td>Rock Type</td>
<td>Sandstone</td>
</tr>
</tbody>
</table>

**Table 1 Triaxial Static Young’s Modulus, Poisson’s Ratio and Compressive Strength**

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Depth (ft)</th>
<th>Effective Confining Pres (psi)</th>
<th>Bulk Density (gm/cm³)</th>
<th>Compressive Strength (psi)</th>
<th>Young’s Modulus (10⁶ psi)</th>
<th>Poisson’s Ratio</th>
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<tr>
<td>31V</td>
<td>7823.60</td>
<td>920</td>
<td>2.185</td>
<td>9983</td>
<td>0.98</td>
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<tr>
<td>27V</td>
<td>7818.90</td>
<td>1830</td>
<td>2.235</td>
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<td>40V</td>
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<td>17668</td>
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**Table 2 Results of Mohr-Coulomb Failure Analysis**

<table>
<thead>
<tr>
<th>Sample Depth (ft)</th>
<th>Confining Pressure $P_c = \sigma_2$ (psi)</th>
<th>Compressive Strength $\sigma_1$ vs. $\sigma_2$</th>
<th>Slope on $\sigma_1$</th>
<th>Unconfined Compressive Strength (psi)</th>
<th>Cohesion (psi)</th>
<th>Angle of Internal Friction</th>
<th>Coefficient of Internal Friction</th>
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<tr>
<td>7823.60</td>
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<td>9983</td>
<td>4.20</td>
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<td>7818.90</td>
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<td>17668</td>
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</tr>
</tbody>
</table>

**Graphs**

- Deviatoric Stress, Strain for Triaxial Test
- Mohr-Coulomb Failure Analysis

- $E = 0.96 \text{Mpsi}$
- $\varphi = 37.95^\circ$
- $c = 1576 \text{psi}$
- UCS = 6457 psi
EDYK-172: rock properties in M2

<table>
<thead>
<tr>
<th>MD 1,300</th>
<th>Stratigraphy</th>
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<th>PA_RHO</th>
<th>DTCO_SF</th>
<th>DTSM_SF</th>
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<th>Pr_sta</th>
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<th>FANG</th>
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Hydraulic fracturing limits

BreakDown Pressure Psi

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<th>Well</th>
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<th>UpperLim</th>
<th>Well_test_before_frac</th>
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<tr>
<td>EDYF097</td>
<td>6400</td>
<td>6900</td>
<td>N</td>
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<tr>
<td>EDYC-094</td>
<td>7700</td>
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<td>Y</td>
<td></td>
</tr>
<tr>
<td>EDYF-117</td>
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<td>7900</td>
<td>N</td>
<td></td>
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<td>EDYG-170</td>
<td>7000</td>
<td></td>
<td>N</td>
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</table>

<table>
<thead>
<tr>
<th>Pozo</th>
<th>Date</th>
<th>Reservoir</th>
<th>CG_psi/ft</th>
<th>FG</th>
<th>ISIP (psi/ft)</th>
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<td>EDYJ-081</td>
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<td>0.57</td>
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<td>EDYJ-072</td>
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<td>EDYJ-071</td>
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<td>M2</td>
<td>0.685</td>
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Geomechanics for M-2 confirmed known stresses

**Preferential Orientation**

\[ \text{SH}_{\text{Azim}} = 120^\circ \pm 9 \]
\[ \text{Sh}_{\text{Azim}} = 30^\circ \pm 9 \]

**Directional Strain Estimation in M-2**
needed to plan for a possible candidate for multi stage frac in Horizontal well in M-2.
Completion techniques

PROJECT DEVELOPMENT – Technology / Completion Options

EDYK-167S1

Challenge Multilayer Reservoir

Conventional Perforating
5 Wells

Hydraulic Fracturing
16 Wells

Propellant
11 Wells

Presenter’s notes: Due to the layering characteristic of M-2 completion strategy should be address to connect those layers. Historically M-2 wells have been hydraulic fractured, perforated with propellant and conventional perforating, results of each technology apply were analyzed in 16 wells HF, 11 Prope, 5 wells Conv Perf.
Graph on the left shows historical production profile by technology. Normalized date indicate an average of 180 bls per day with conventional perforating which represent 178 mbls of cumulative oil production. When the well is perforated with propellant the average production is 250 bopd with a 200 mbls of cumulative production. And the third technology applied which is HF shows an average of 430 bopd with a cumulative production of 300 mbls. These results lead to choose hydraulic fracture as the best completion technique.
To date, 33 wells have been completed in M-2, where 12 were hydraulic fractured, 13 perforated with propellants, with high shot density perforation and 7 Planed Workovers to 2015. Hydraulic Fracturing has commonly been applied in Ecuador as an alternative to reduce formation damage, requiring a pre and post-frac evaluation.

Planed Workover
EDYD-085
EDYG-036
EDYG-046S1
EDYH-150H
EDYT-154
EDYT-158
Development & optimization

Ecuadorean regulatory agency approved Hydraulic Fracture Jobs without a Pre and Post – Frac Evaluation for M-2 laminated Reservoir.
Ecuadorian regulatory agency approved Hydraulic Fracture Jobs without a Pre and Post – Frac Evaluation for M-2 laminated Reservoir.
Development & optimization

Reduction in operative costs and deferred production

Ecuadorean regulatory agency approved Hydraulic Fracture Jobs without a Pre and Post – Frac Evaluation for M-2 laminated Reservoir.
Productivity Index Statistics and Hydraulic Fractured Evolution

PREVIOUS HF WELLS

OPTIMIZED HF WELLS

PI (BOPD/psi)

EDYU-071 M2
EDYU-072 M2
EDYU-081 M2
EDYU-180 M2
EDYU-084 M2
EDYU-117 M2
EDYU-171 M2
EDYU-097 M2
EDYK-16751 M2

(BOPD)

BFPD
BOPD

Propant Sacks (x)

Production (BPD)

bbl/d*psi*ft

EDYU-070 M2
EDYU-071 M2
EDYU-072 M2
EDYU-081 M2
EDYU-180 M2
EDYU-084 M2
EDYU-117 M2
EDYU-171 M2
EDYU-097 M2
EDYK-16751 M2
5 hydraulic fractures: 1200 BOPD incremental

Previous wells on production: 10
EDYK-126: Hydraulic fracture
EDYG-171: Hydraulic fracture
EDYF-117: Hydraulic fracture
PROJECT DEVELOPMENT – Hydraulic Fractured Wells in M-2

Production Normalized Hydraulic Fractured Wells, BOPD

- 8 Wells performed with Workflow Analysis
- Previous, 5 Wells performed
- 3 Wells performed with No-Workflow Analysis
Based on the analysis of reservoir pressure, net pay, productivity index, among others, 21 wells were identified as WO candidates after the analysis of a total of 185 existing wells. Map to the left shows in red the location of the WO candidates. Since one of the project's goals was to identify new opportunities, WO and new wells' location were analyzed in this slide.
Results & Value

- **Results**
  - M-2 new reservoir characterization unveiled excellent reservoir characteristics for those thin beds (Φ=20%, K up to 1.5 Darcy).
    - Glauconite and Calcite are not a primary concern in the best reservoir quality and are present mainly in less saturated low porosity reservoir.
  - A comprehensive multidisciplinary workflow is now available for workover selection and ranking (applicable also to other secondary reservoirs).
  - Improved Hydraulic Fracture Design for M-2
  - This winning strategy for M-2 development was designed and successfully implemented in 4 months.

- **Value**
  - **1,200 Barrels** of incremental oil in 5 wells.
  - For the entire M-2 development strategy the impact will be:
    - **5MM BIs** considered as incremental oil,
    - Workover cost savings and reduction of deferred production for next campaigns
  - Increase the M-2 reservoir reserves from 14 to 19 MMBIs as well as its recovery factor to 18%
  - Maximize Eden Yuturi opportunities optimizing water management strategies

Presenter's notes: Since then three wells had been fractured without pre-frac evaluation, post-frac production meeting production prognosis and productivity index range.
Unlocking laminated reservoir full potential, increasing connectivity with fracture.