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A Methodology to Design Exploratory Wells

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Petrobras SA
Topics

• Introduction

• Well Management Process
  – Matrix of Criticality
  – Processes
    • Engineering
    • Operation
    • Safety

• Case Study

• Conclusions
Introduction

- Depletion of old field
- New opportunities
- New frontiers
- High cost of the drilling rigs

- Expensive Wells

- Cost Reduction
- Underestimate the well design
- Loss of the well
- Reconstruct a new well

- Unexpected Increase in Cost
<table>
<thead>
<tr>
<th>Wild Cat Wells / Country</th>
<th>Year</th>
<th>Safety Related Problems</th>
</tr>
</thead>
</table>
| **Well-1** (Country 1) Shallow Water | 1 | Actual pore pressure higher than predicted pore pressure → kick  
Rig and well design considered inappropriate  
Well reach TD but time and cost much higher than forecast  
Lack of methodology and “well robustness” was low |
| **Well-2** (Country 1) Shallow Water | 2 | Kick. No barite during the well control operation.  
Rig and well design considered inappropriate  
Well did not reach TD  
Lack of methodology and “well robustness” was considered low |
| **Well-3** (Country 2) Deepwater | 2 | Lithology: predicted and actual did not match. Temperature much higher than expected. No pore pressure specialist at the rig site. Well did not reach TD  
“Well robustness” was considered low |
| **Well-4** (Country 3) Deepwater | 3 | New systematic for designing wells  
Great emphasis on reducing geopressure uncertainties  
Three independent geopressure studies were performed  
Well reached TD within the forecasted time and cost |
Objective
Well Management Process (WMP) based on Petrobras Best Practices

The final goal of the WMP is to construct the well that safely reaches its targets within the expected time and cost.
Well Management Process

Matrix of Criticality

Well Engineering
Well Design
Support
Safety
Logistics
Execution
Well Operation

Timeline
Planning → Execution
Matrix of Criticality
Matrix of Criticality

Well Complexity Index

Well Robustness

Extra Casings

Mitigating Actions

Matrix of Criticality
Well Complexity

The **Well Complexity Index (WCI)** is used to quantify the geological, operational and logistics risks associated to the drilling of a well.
Well Complexity Index (WCI)

- Logistics
- Water Depth
- Temperature
- Pore and Fracture Pressures
- Number of Well Drilled in the Area
- Shallow Hazards
- TVD
- Etc.
Well Robustness (WR) is the combination of the number of casing strings and the mitigating actions that the company must follow to guarantee the success of the well.

<table>
<thead>
<tr>
<th>Well Robustness</th>
<th>Number of Extra Casings</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
</tr>
</tbody>
</table>

More Robust
Well Robustness versus Extra Casings

Example

WR = C

Two Extra Casing Strings

Casing shoes based on Company Procedures

Two Extra Casings Due to WR = C
## Well Robustness versus Mitigating Actions

### Mitigating Actions for Different Well Robustness

<table>
<thead>
<tr>
<th>Item</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic for GP</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>GP Models</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Real Time GP</td>
<td>-</td>
<td>-</td>
<td>24 / 7</td>
<td>24 / 7</td>
</tr>
<tr>
<td>Company Man Experience</td>
<td>5 years</td>
<td>5 years</td>
<td>15 years</td>
<td>20 years</td>
</tr>
</tbody>
</table>

GP - Geopressure

WR = C
## Well Robustness versus Mitigating Actions

<table>
<thead>
<tr>
<th>Item</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lost Circulation</td>
<td>-</td>
<td>-</td>
<td>Specific DT prepared</td>
<td>Specific DT prepared</td>
</tr>
</tbody>
</table>

DT – Decision Tree

WR = C
Example of Decision Tree

DECISION TREE FOR LOSSES WITHOUT GAS HIGH GLR

Loss

Loss > XX BPH

NO

TREATMENT A BAROID WHILE DRILLING AHEAD

DRILL AHEAD

YES

SUCCESS?

PARTIAL

NO

TREATMENT B BAROID WHILE DRILLING AHEAD

DRILL AHEAD

YES

SUCCESS?

NO

PROCEDURE 2

(WELL CONTROL WITH CATASTROPHIC LOSSES AND POSSIBLE FLOW CELL)

1. Close middle pipe ram to prevent collapse of the riser and to reduce the volume of mud lost to the formation;
2. Read PTT (Acoustic sensor above the middle pipe ram) to define fluid level in the riser and the volume lost to the formation;
3. Read PTT (MUX sensor under middle pipe ram) to define equivalent pressure in the probable lost circulation or permeable zones; static level in the wellbore.
4. Displace fine, medium or coarse (if possible) LCM plug;
5. Reduce mud weight as low as possible;
6. Control ECD with the APWD always comparing with fracture gradient curve;
7. Displace cement plug if previous actions don’t reestablish circulation then

TREATMENT C BAROID

DRILL AHEAD

YES

SUCCESS?

NO

VERIFY THE SUCCESS

TREATMENT D BAROID

DRILL AHEAD

YES

SUCCESS?

NO

VERIFY THE SUCCESS

SET CONTINGENCY

1
**MUD TREATMENT TO COMBAT LOSSES**
*(FROM LOW TO HIGH SEVERITY)*

**TREATMENT A (NO PBL)**

50 ppb Calcium Carbonate Fine in drilling fluid as sweeps.

OR

Spot 25 bbls of pill

Calcium Carbonate F 10ppb
SAFE CARB 20 20 ppb
SAFE CARB 40 20 ppb

OR

Mica F 5ppb
Mix II Fine 7 ppb
SAFE CARB 250 7 ppb
Nut Plug F 7 ppb

**TREATMENT B**

NO PBL
SAFE CARB 40 5 ppb
SAFE CARB 25020 ppb
SAFE CARB 600 20 ppb
SAFE CARB 1000 20 ppb

**NEED PBL**

Mica M 10 ppb
Mix II Med. 10 ppb
Mix II C 10 ppb
SAFE CARB 2000 20 ppb
Nut Plug F 10 ppb

**TREATMENT C**

NO PBL FOR CONCENTRATION 1-4 PBB
CEM-NET (MUST BE IN FRONT OF THE LOSS ZONE)

OR

NO PBL
FORM – A- SQUEEZE (Calcium Carbonate)

OR

DISCUSS WITH SCHLUMBERGER ABOUT THE USE OF PBL
FORM – A- SET

OR

DISCUSS WITH SCHLUMBERGER ABOUT THE USE OF PBL
FORM – A- PLUG II

**TREATMENT D**

DISCUSS WITH SCHLUMBERGER ABOUT THE USE OF PBL
SODIUM SILICATE/Calcium Chloride/ Cement

OR

NEED PBL
BARITE PLUG

**TREATMENT E**

NEED PBL
GUNK SQUEEZE
Matrix of Criticality

Robustness

<table>
<thead>
<tr>
<th>Complexity Index</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>WD</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Drilling Allowed
- Drilling with Restrictions
- No Drilling

WD = Well Design
Well Engineering Process

Well Design and Engineering Support
Well Engineering Process

Conceptual Phase

- Start Well Meeting
- G&G
- Directional
- Geopressure and Geohazards
- Casing Shoe Setting Depths
- Well Design Alternatives (Time and Cost)

Engineering Phase

- Study Meeting
- Casing Design
- Well Head
- Cementing
- Drilling Fluids
- Bit and BHA Programs

Detailing Phase

- Formation Evaluation and AFE
- Peer Review
- Drilling and Evaluation Program

Execution Phase

- DWOP
- Execution
- Close Out
Well Safety Process (WSP)

The main goal of the WSP is to guarantee that all Company Safety Requirements are implemented in all phases of the project.

(from planning to execution)
Well Safety Process

• Operator Standards and Best Practices

• Well Control Specialists

• Prevention and Response

• Well Control Emergency Response Plan
  – Implemented to guarantee that the entire drilling team is well trained
Well Control Emergency Response Plan (WCERP)

The Operator Must Be Prepared for Any of These Situations ...

Small Kicks ............... Large Kicks .................. Blowout

Level 1 .................. Level 2 ........................ Level 3

Simple well control situation requiring only the use of the Drillers Method

Complex well control situation requiring actions such as direct intervention, relief well or capping
Well Control Emergency Response Plan
(Blowout Control)

(Level 3 Situation)

- Simple small water kick
- Direct Intervention
- Relief Well
- Capping

The Operator Must Be Prepared for This ...
Figure 5 – Sample directional and intercept design for a relief well.
Capping
Capping
Capping
The Black Sea Project

4 C

Well Complexity Index

Well Robustness
The Black Sea Project

Black Sea
Turkey

Petrobras Headquarters
Rio de Janeiro
Brazil
The Black Sea Project

Turkey

Istanbul

Ankara

Well

Black Sea

Water Depth = 2200 meters (7,218 ft)
Ultra Deepwater Well

600 km (375 miles)

500 km (312 miles)

450 km (281 miles)

Nearest well
Characteristics of Ultra Deepwater Wells of Complexity 4

• Small operational window (pore and fracture pressures very close)
• High rate of penetration (ROP)
• Long time for tripping
• Tendency to display high non productive time (NPT)
• Generally NPT higher than 40% (GoM)
Black Sea Challenges

• Drilling
  – Expected shallow gas intervals
  – Long abnormally pressurized intervals
  – Low fracture pressure gradients
  – Expected severe lost circulation zones
  – Great potential for false kicks
  – Risk of gas migration through the riser
Well Engineering Process

Well Design
Geopressure: The Black Sea Well

Interval Velocity acquired for Pore Pressure Purpose

Depth (m)

DT (us/ft)

Abnormal Pore Pressure Mechanisms

Fault

Lateral Transfer

Shallow Gas

Under compaction

Abnormal Pressure Interval
Mitigating Actions to Reduce Geopressure Related NPT

• Shallow Intervals (above surface casing)
  – Conduct Shallow Hazard Study

• Deeper Intervals (below surface casing)
  – Use seismic velocity adjusted for pore pressure purpose only
  – Identify abnormal pore pressure mechanisms
  – Conduct independent estimates
  – Create scenarios using different interpretations
Geopressure: Independent Studies

Narrow Operational Window

Depth = D
Well Design Considerations

- Shallow Gas Interval Kick Tolerance
- Lithology
- Loss Circulation
- Differential Pressure Targets

Forecast

Fracture

Pressure’s peak foreseen

Pore

\[ \text{WCI} = 4 \]
\[ \text{WR} = \text{C} \]
Well Operation Process

Logistics
Well Operation: Logistics

– Plays primary role in well operation
– Frontier area with no offshore infrastructure
– Mobilization of the drilling rig to the Black Sea
  • **Challenge**: Pass the rig below the existing bridges of the Bosphorus Straits, Turkey
Drilling Rig - Mobilization

- Rig received and derrick disassembled in Olen, Norway;
Drilling Rig - Mobilization

- Rig received and derrick disassembled in Olen, Norway;
- Rig navigated more than 4,000 nm to the Black Sea;
Drilling Rig - Mobilization

- Rig received and derrick disassembled in Olen, Norway;
- Rig navigated 4,130 nm to the Black Sea;
- Rig passed underneath the existing bridges of the Bosphorus Straits;
- Derrick reassembled in the Black Sea, Turkey.
- Rig Mobilization = 117 days
Well Operation: Logistics

Bosphorus Straits

Drilling Rig Mobilization
Well Operation and Engineering Processes

Execution and Engineering Support
Execution and Engineering Support

• Mitigating Actions
  – Special procedure created to drill the shallow gas interval
  – All operation planned in Advance
  – Decision Trees developed to mitigate problems for each operation
  – Robust Real Time Surveillance System implemented to increase safety and reduce NPT
Robust Real Time Surveillance

Legend
- Decision
- Technical Support
- Pore Pressure
- Data

Decision Support Center
Head Quarters
(Rio de Janeiro)

Pore Pressure Specialists
(Aberdeen)
24/7

Operational Office
(Ankara)

Rig Site
(Black Sea)
24/7
Robust Real Time Surveillance
Results
## Results

<table>
<thead>
<tr>
<th>Fact / Incidents</th>
<th>Observation</th>
<th>Lesson Learned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow gas zone drilled without incidents</td>
<td>Good well planning.</td>
<td>Adequate Well Robustness</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most of the expected problems (kicks, losses, etc.)</td>
<td>Mitigating actions, such as the use of Decision Trees,</td>
<td>Adequate Well Robustness</td>
</tr>
<tr>
<td>were successfully controlled.</td>
<td>were effective</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All planned casing were run due to well conditions</td>
<td>Extra casing available as needed</td>
<td>Adequate Well Robustness</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kick occurred while drilling a fault zone</td>
<td>Geological issue</td>
<td>Improve geologic prognosis for drilling purpose. <strong>Improve well control response.</strong></td>
</tr>
</tbody>
</table>
Results

Difference between Prognosis and Actual at the Peak = 6.6 %
## More Results

<table>
<thead>
<tr>
<th>Project in Numbers</th>
<th>Planned</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total depth (meters)</td>
<td>5,525 / (18,127 ft)</td>
<td>5,531 / * (18,147 ft)</td>
</tr>
<tr>
<td>Duration (days)</td>
<td>152</td>
<td>162</td>
</tr>
<tr>
<td>NPT (%)</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>Number of casing strings</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>

PPGI = 1.066 (at the peak)

* Considered unplanned operations (VSP, MDT, etc.)

PPGI = Pore Pressure Gradient Index = Actual PP / Expected PP
More Results

The Well Management Process was applied in other three wells drilled in three different countries.

All wells were drilled without major incidents, safely reaching their targets within the expected time and cost.
Conclusions

• Petrobras Well Management Process has proved to be effective as a management methodology

• Quantifying the right well complexity and well robustness helped define the required resources to effectively reach the objective of the well (safety, time and cost)

• Mitigating actions used during the planning and the execution phases were also valuable
The End

Questions?