Case Study analysis of Geological Operations Lessons Learned

29 October 2013
Jaguar-1 Well

Summary

GENERAL DATA

- Well Name: Jaguar-1
- Location: Offshore Guyana → Remote area
- Water Depth: 207ft → Shallow Water
- Offset Well: Abary-1 (9.5Km East)
- Wildcat (below the Maastrichtian)

PLANNING OPERATION

- Spud expected in Q2/2011
- TD: 21,435ft
- Top Reservoir: 18,750ft (Cret1-Tur)
- Expected PP @ TD=15ppg (16700psi)
- Expected BHT @ TD=444F

ACTUAL OPERATION

- Spud in Q1/2012
- TD: 15,998ft
- Top Reservoir: Not reached
- PP at 15998ft=18.7ppg (15556psi)
- BHT at 15998ft=342F
Jaguar-1 Well
Summary

Operating Environment and HPHT Projects

*Ultradeep HP/HT Completions: Classification, Design Methodologies, and Technical Challenges. Maldonado et al. 2006
Jaguar-1 Formation Evaluation

Wireline

Schlumberger HPHT Tools (SPE 97571) 2005:

- 25,000 psi / 350°F
  - CMR* – Magnetic Resonance
  - OBMI* – Oil Based MicroImager
  - DSI* – Dipole Shear Imager
  - MSCT* – Mechanical Sidewall Coring tool
  - VSI* – Versatile Seismic Imager
  - USI* – Ultrasonic Imager – Cased Hole

- 25,000 psi / 500°F
  - ECS* – Elemental Capture Spectroscopy
  - XTREME* suite of Quad-combo

- 30,000 psi / 400°F
  - MDT* string – Modular Dynamic Tester tool

- 30,000 psi / 500°F
  - CBL – Cement Bond Log
  - HAPS* – Hostile Array Porosity

Since 2005, many tools have been upgraded to HPHT.
- Dipole Sonic (DSIHT and HTDSI)
- SWC
- MDT-Forte (400F) and 3XV (500F). Still missing the Fluid Analyzer above 350F.

For Jaguar-1 the HPHT tools were planned and rented for the lower sections. However, due to the anticipated TD of the well, most of the tools were not used.
Jaguar-1 Lessons Learned

AGENDA

Jaguar-1 Well
   Introduction (Prognosis and Results)
   Pore Pressure Curve
   Reasons for Abandonment

Geological Operations
   • Formation Evaluation Data
   • Pore Pressure
   • Temperature

Lessons Learned / Conclusions

Well Control Operations Lessons Learned
Jaguar Pre-Drill

Jaguar-1 Basic Data / Lithological Column

Well Name: JAGUAR-1
Classification: Exploration, Vertical, Commitment
Operator, %: Repsol 15% (Operator)
Partners, %: YPF 30%, Tullow 30%, CGX 25%
Country: Guyana
Basin: Guyana-Suriname
Block Name: Georgetown
Water Depth: 207 ft
KB: 102 ft
Total Depth: 21,435 ft MDKB
Geological Play: Coniacian/Turonian Basin Floor Fan Stratigraphic Trap
Formation Evaluation: LWD: Schlumberger
Wireline: Schlumberger
Mud Logging: Geoservices
Offset Wells: Abary-1
Jaguar-1 Pore Pressure

Pre-drill vs Actual

TD=15,998ft
Jaguar-1 Abandonment
Recommendation from Drilling

SUMMARY:

TD : 15998 ftMD (15894.41 ft TVDSS) – Driller’s depth
16015 ftMD (15911.41 ft TVDSS) - Logger’s depth

Spud: February 7th, 2012
Reached TD: July 08th, 2012
Demob: July 30th, 2012

PP at TD: 18.7 ppg
BHT: 342 F (Horner plot at TD)

Recommendation

If the calculate pore pressure at this depth, as per attached document of our pressure expert, is confirmed and also taking into the consideration the risk, declared at same document, of pressure ramp slope, that could increase the PP up to 18.7 ppg, it is a fact that we find another pressure ramp.

Considering:

- The objective fixed when the running liner decision was taken, has been completed because now it is known the pressure behavior, which being the worst from among the three possible scenario, restricts the achievable depth.
- The risk associated to drill deeper are:
  - A clear weakening of the well integrity by the increment of the pressure that affect specially at the surface, 10K seal and 10½” casing exposed. To supersede it, the 9½” tie back could be run and 15K spool make up but, it will limit drastically the flow rate thinking on use above 19.0 ppg mud.
  - As per M1 notice, the current mud system become instable above 19.0 ppg, then an Hematite system is required, not available on site, we do not know how long could take to build up the necessary amount.
  - If confirmed the permeability of the zone, the possibility of a massive kick is high. It together with the weakening above described, bring the well control situation much more risky than before.
  - The difficulty to abandon this well, as permanent abandon, became more difficulty if we drill a permeable zone, it maybe will drive to case the open hole before abandon.
  - It is very poor the add value of the light that some few additional feet could bring on, because it is clear that the unknown limit of the ramp makes unachievable the main target at 18,000ft. If this add value is comparing with the mayor risks
Jaguar-1 Lessons Learned

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Lessons Learned / Conclusions

Well Control Operations Lessons Learned
Jaguar Prospect
Geological Model

Jaguar–1 attempted to target Repsol’s main working play concept of the Georgetown Block and for the region. It is the first Suriname-Guyana Basin well designed to penetrate an interpreted thick Middle Cretaceous deepwater “basin floor” fan sandstone reservoir with a viable hydrocarbon stratigraphic trapping geometry.
Jaguar-1 Formation Evaluation

Introduction

LWD: Pore Pressure RT

LWD: Pore Pressure RT

LWD: Pore Pressure RT, CSG Point

LWD: Pore Pressure RT

WL: Reservoir Evaluation (if pay)

LWD: Pore Pressure RT

WL: Reservoir Evaluation (if pay)

LWD: Pore Pressure RT, CSG Point, Reservoir Evaluation (if pay)

LWD: Pore Pressure RT, Reservoir Evaluation (Firm)

HPHT

Correlation with Abary-1

No offset Wells

Large Hole
Jaguar-1 Results
Logging Evaluation Inventory

<table>
<thead>
<tr>
<th>Depths – MD (ft)</th>
<th>LWD</th>
<th>WL</th>
</tr>
</thead>
<tbody>
<tr>
<td>26x28in &amp; 21in Sections (509 – 5,050)</td>
<td>GR, Res</td>
<td></td>
</tr>
<tr>
<td>16.5x19in Section (5,050 - 9,500)</td>
<td>GR, Res, Sonic</td>
<td>VSP (lookahead)</td>
</tr>
<tr>
<td>14 ½ x 17 1/2in Section (9,500 – 10,972)</td>
<td>GR, Res, Sonic</td>
<td></td>
</tr>
<tr>
<td>12 ¼ x 14 ¾ Section (10,972 – 14,479)</td>
<td>GR, Res, Sonic</td>
<td></td>
</tr>
<tr>
<td>10 5/8 x 12 ¼ Section (14479 – 15570)</td>
<td>GR, Res, Sonic</td>
<td></td>
</tr>
<tr>
<td>8.5in Section (15570 – 15998)</td>
<td>GR, Res</td>
<td></td>
</tr>
</tbody>
</table>

TD=15,998ftMD

Large Hole
HPHT
Jaguar-1 Formation Evaluation
Pressure increase in 10 5/8in Section

SEQUENCE of OPERATIONS

- Drilling 10 5/8in Section from 14,479ft with MW=15.5ppg
- POG and FG ~ 1-2%
- ↑ MW to 16.1ppg at 14800ft
- ↑ MW to 16.2ppg at 15200ft
- FG = 6.5% at 15520ft
- POG = 56.2% at 15448ft
- ↑ MW to 17.4ppg after.
- POG 68% 15550ft
- STOP for LOGGING OPERATIONS
Jaguar-1 Formation Evaluation
10 5/8 x 12.25 in Section

Wireline Logging:
Run #3A: AIT-EMS-PPC-GPIT-MSIP-GR
Run#3A: CBL (with MSIP tool)
Run#3B: CMR-LDS-CNL-HNGS
Run#3C: GR-VSI
Run#4A: HNGS-EMS
Run#4B: GR-MDT

Shales and sands.
No porosity with Standard logs
MDT run for Drilling Purposes

MDT REMARKS:
- 32 Attempts: 10 lost seal, 15 tight, 5 supercharged, 2 good.
- No mud cake - LOW PERMEABILITY

GOOD MDT point at 15442’ MD-WL
LFA interpreted as oil @ 15,442’ MD-WL.

Current interpretation: oil in thinly laminated formations.
Jaguar-1 Formation Evaluation

MDT - Pressure build up at 15442.25 ft (logger’s)
Jaguar-1 SWC @ 15442.5ft

SWC @ 15442.5ft Ingrain Analysis + OBMI
**Jaguar-1 Operations Summary**

8.5in Section (15570ft – 15998ft)

**SEQUENCE of OPERATIONS**

- Drilling 8 1/2in Section
  - MW= 18.3 ppg, ECD = 19.1 ppg

- Observed CG= 50%

- Started to increase mud weight to 18.6+ ppg.

- Short trip to 15510ft

- Circulated bottoms up at 500gpm, 4700 psi.
  - Max gas recorded 23.5%.

- Short Trip Gas = 25%, MW=18.6 ppg (ECD 19.4)
Jaguar-1 Formation Evaluation
8.5in Section

Logging:
Run #7A: QAIT-PPC-MSIP-GPIT-GR
Run#7A: CBL (with MSIP tool)
Run#7B: HLDS-HASP-HNGS
Run#7C: DOBMI-GR
Run#7D: CMR-GR
Run#7E: MDT-FORT-GR
Run#7F: VSI-GR
Run#7G: MSCT-GR

Shales and sands.

LFA oil @ 15,955’ MD-WL. Lab confirmed.

Current interpretation: oil in thinly laminated formations.
Jaguar-1 Pore Pressure

Data Validation

Jaguar-1 well data

Loaded:
- Logs (GR, DT, Rho, Cal, Res, NPHI)
- MDT
- Casing
- Markers (chronostrat)
- Mudweight (taken from mudlog)
- Deviation
- Leak Offs/Fits
- Kicks, losses
- Temperature data
Jaguar-1 Pore Pressure
Drilling Events

- Pore Pressure in shale calculated from Sonic and Resistivity showed Lower Pore Pressure than shown in permeable zones from drilling shows and MDT.

- Pore Pressure in Permeable zones determined with Drilling Events (Kicks and Gas Shows) and Logging Evaluation (MDT).

DRILLING AND LOGGING EVENTS:

- Kick @ 7,484ftMD
- Kick @ 8,532ftMD
- POG @ 15,550ftMD = 68%; MW=17.4ppg
- MDT @ 15,442ftMD = 17.4ppg
- FIT @ 15,550ftMD = 19.81ppg
- STG @ 15,998ftMD = 25%; MW=18.6+ppg
- MDT @ 15,955ftMD = 18.7ppg
Jaguar-1 Pore pressure
Predrill Offset Well Correlation
• **Seismic velocity data**
  • Compresional Sonic and checkshot are in good agreements.
  • Detailed velocity variation is lost in the 3D interval velocity possibly due to low seismic resolution or lack of reflectors.

• **Calibration**
  • Offset well Abary-1 data was primarily used to calibrate the pore pressure and stress for the planned Jaguar-1.

• **Pore Pressure Prediction**
  • A shale overpressure ramp starts at ~4000ft and gradually increases to ~11ppg at Burdigalian formation top. Following a pressure reversal to 10ppg, gradually increases to ~15.6ppg at TD.
  • Additional overpressure due to source rock may exist near Cretaceous reservoir. However it cannot be modeled quantitatively due to data limitations.
  • 3 cases are presented for centroid and buoyancy effects in the sand formation due to uncertainty in sand continuity.
  • Limestone formations are assumed to be impermeable.

• **Uncertainties**:
  • Uncertainty in pore pressure exists due to low resolution interval velocity.
  • 3 different sand structural continuities are assumed for the centroid calculations but sands may not be continuous. Further geological analysis is required.
  • Additional overpressure due to proximity to the source rock may exist near Cretaceous reservoir. However the amount of overpressure is uncertain and cannot be calculated using compaction trend techniques.
  • Limitation are assumed to be impermeable. However losses can be encountered if permeable zone exists.
1. The Source rock is actually in the HC generation window.
2. The seal is effective.
3. Overlying shale Pe is 90% of the computed Frac Pressure.
4. The reservoir zone is a single hydrocarbon column, considering that the turbidite bodies are connected, due to the stacking and/or the high net/gross.
Jaguar-1 Pore Pressure
IKON Post mortem results

- **Bowers loading** is predicting lower pressures than Equivalent depth and Eaton below ~8500 ft. Above this it is close (but generally slightly above) mud weight.

- **Equivalent Depth Method** predicts near mud weight to around 14000 ft, then under predicts deepest pressures.

- **Eaton method** predicts (exp 3) higher pressures all way down borehole. Still underestimates pressure near TD, but closer then Equivalent Depth Method.
Combined Velocity vs Density cross plot for Jaguar-1 and Abary-1. Yellow outlined region suggests increased density shale behaviour consistent with secondary mechanisms as pressure source.

Mineral transformations are known to generate secondary overpressure in shales once the temperature is above 80ºC and is most significant over temperatures 100-120ºC. The best known and studied example is smectite transforming to illite. Secondary overpressure generated by such mineral transformation is not “detected” by a traditional log-based shale pressure prediction study based on porosity/effective stress such as Eaton and Equivalent and Bowers loading models. Therefore recognition that secondary mechanisms are active is critically important to the pressure analysis process. Once identified, their overpressure contribution can be estimated.
Jaguar-1 Temperature Gradient is 1.72F/100ft (31.4C/Km).
Jaguar-1 Temperature
Temperature at Present Day

- Offshore, isotherms are sub-parallel to sea-floor.
- Onshore, the thermal gradient decreases.
- This decrease is partially due to the presence of thick sand beds.
- Sands have higher conductivities than silts and shales.
A conceptual model of several Normal Compaction Trends, linked to diagenetically changing chemical compositions with depth, is highlighted by plotting effective stress against velocity data. Applying these different NCTs to the relevant depth intervals shows an increase in overpressure with depth which more closely predicts the pressures seen at Jaguar-1. The 'hottest' diagenetic model can probably be used to extrapolate to greater depths.

This model may be helpful when planning further exploration wells. The local calibration to Jaguar-1 has not been tested elsewhere but the approach has been used elsewhere in high temperature wells.
Jaguar-1 Pore Pressure

Conclusions/Lessons Learned

• Jaguar-1 HPHT Well was stopped earlier due to High Pore Pressure found during the Drilling.
• Jaguar-1 Geological Operations provided a full set of logs/information for logging interpretation.
• MDT was crucial in this well to confirm Pore Pressure in permeable zones and to provide G&G the geological information to review the prospect.

• Wireline logs were successfully run within the HPHT range.
• Wireline MDT practices were reviewed for the HPHT near balance conditions.
• High Pore Pressure Model is difficult to predict in a wildcat. However, the recognition of the chemical compaction as a secondary mechanisms is critically importance to the pressure analysis process.
Jaguar-1 Lessons Learned

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Well Control Operations Lessons Learned
This EKD is composed of a 12” Coriolis mass flow meter and a 12” by-pass circuit isolated with two 12” valves (inlet & outlet) remotely controlled from a pneumatic manifold situated on deck at the back of the Mud Logging Unit.
Jaguar-1 – Geological Operations

EKD - FingerPrints

EKD – FingerPrint at the beginning of each section.

EKD – FingerPrint while drilling operations.
At around 16hr10, some variations of WOB, Torque and ROP start and are soon followed by an increase of the flow out measured by the EKD (16:14hrs). Flow check at 16h24, and then the well is shut in at 16:29hrs.
Jaguar-1 Lessons Learned

Well Control Operations Lessons Learned

• Jaguar-1 had two kicks in the shallower sections.
• The Early Kick Detection system from Geoservices worked to identify immediately the influx.
• Flow check was performed.
• The flow check should be avoided in the HPHT sections.
Thank you