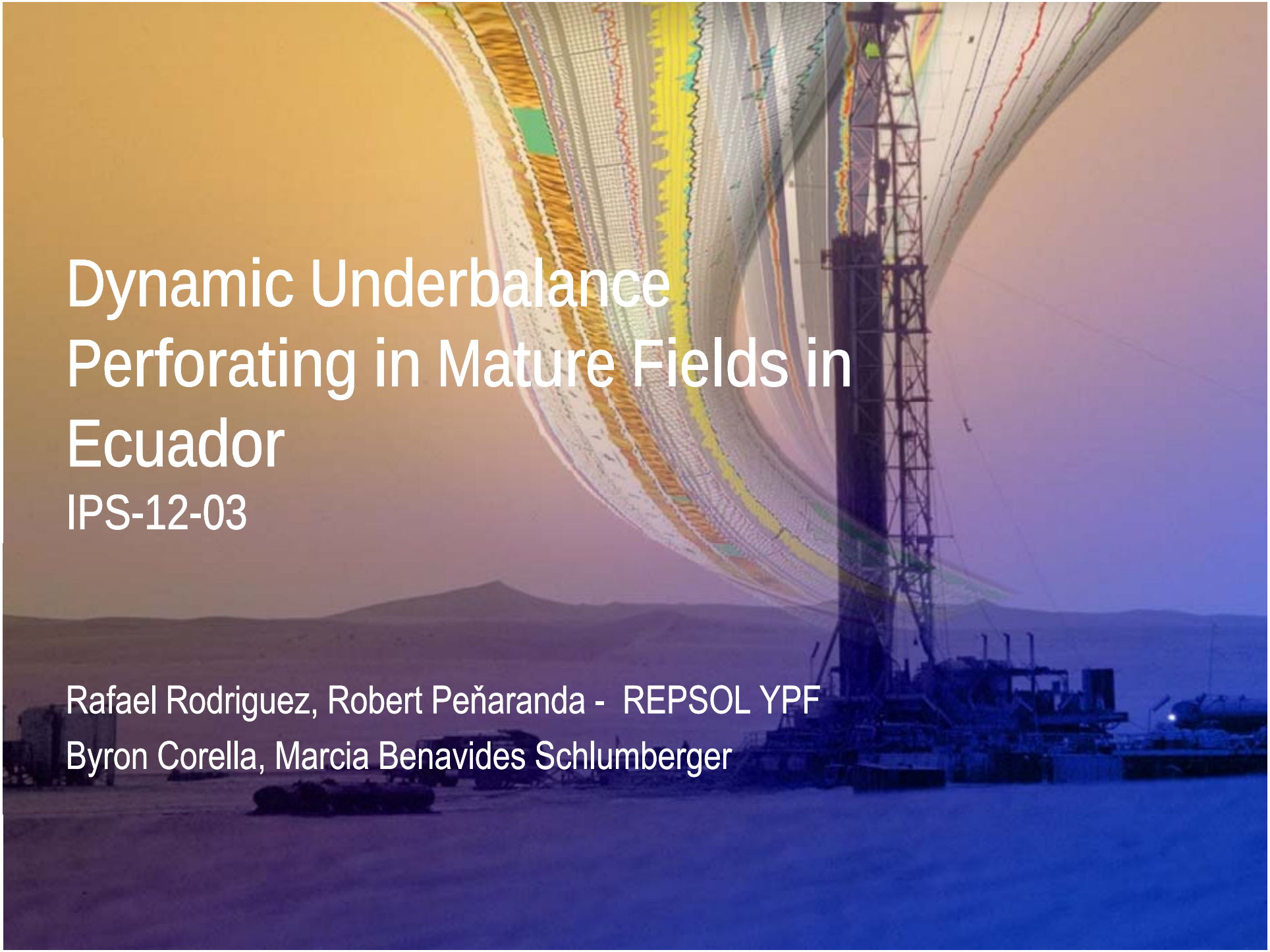

Dynamic Underbalance Perforating in Mature Fields in Ecuador

IPS-12-03

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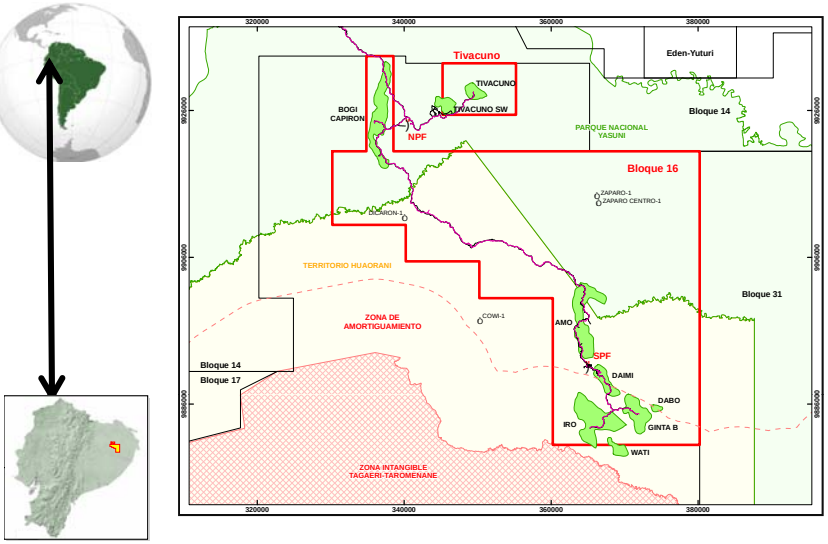
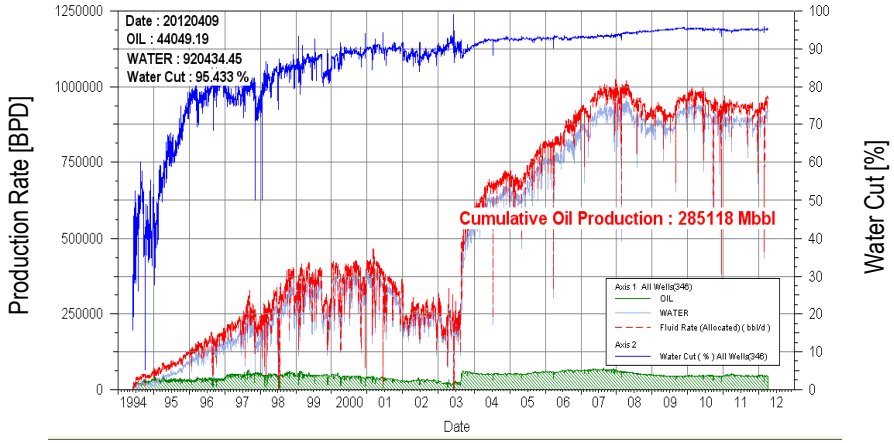
Byron Corella, Marcia Benavides Schlumberger

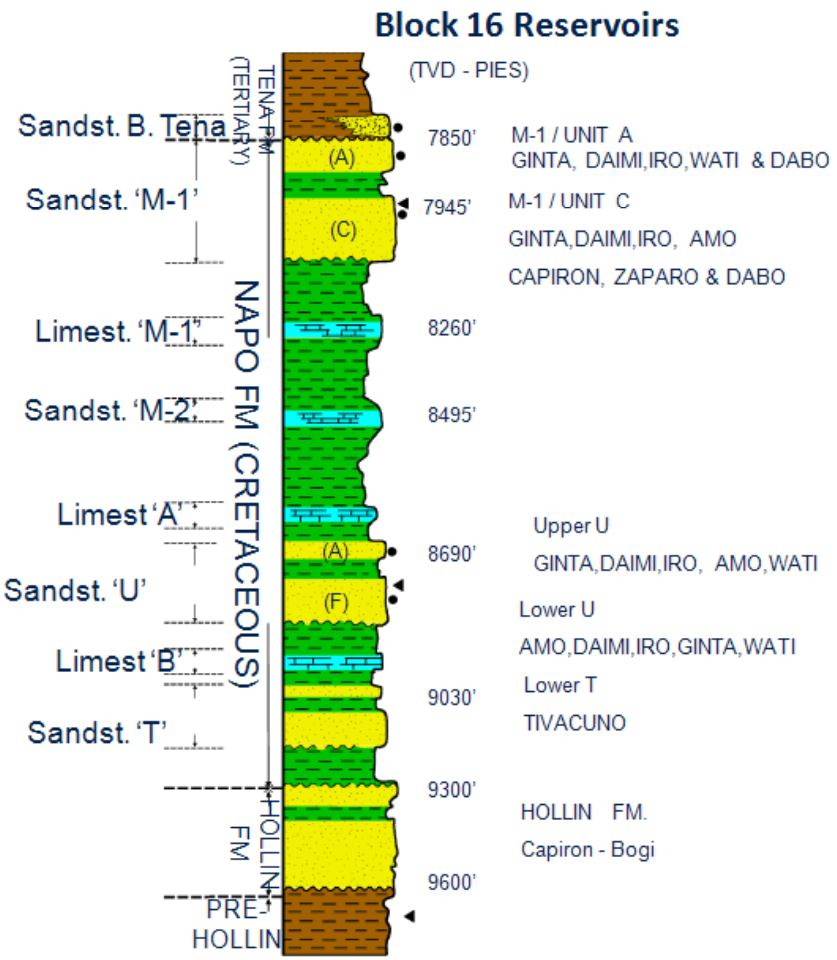
Field Overview





- Central West Ecuadorian Basin
- Discovered in 1994
- OOIP: 1,605 MBbls
- Maximum production rate: 65,200 bopd in year 2007

Field Overview



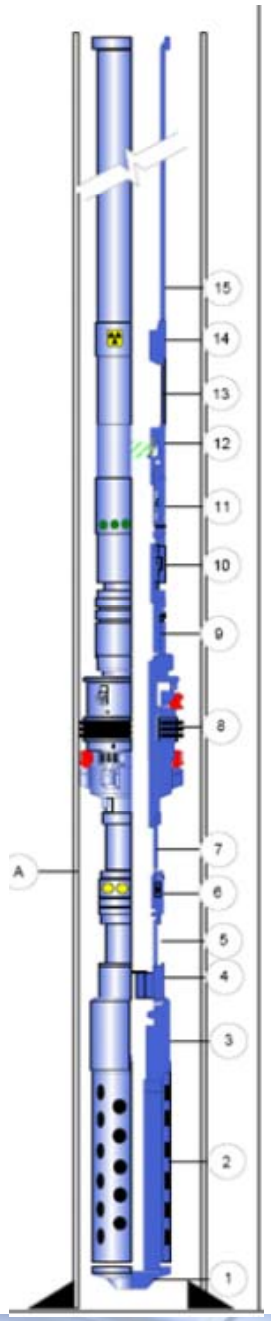
- 4 main reservoirs and % Oil Cum.:
  - Basal Tena 2%
  - M-1 60%
  - Napo U 34%
  - Napo T 4%
- Actual conditions:
  - Active wells: 158
    - Directional wells: 77
    - Horizontal wells: 81
- Production: 44,834 bopd
- BSW: 95%
- Recovery factor: 21%

Objectives and Challenges

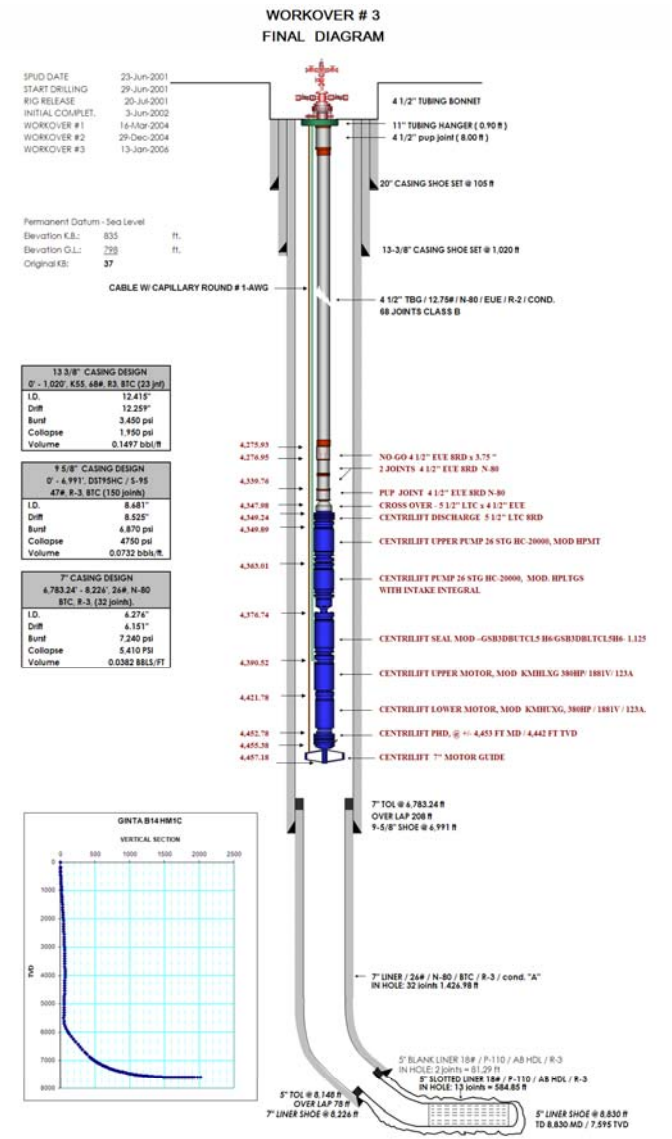
- Mature field producing at high water cut from the main reservoirs
- Complete and test Upper U and Basal Tena with promising potential for oil production at low water cut but also with less favorable petrophysical properties
- Achieve sufficient production to install dual completions
- Tubing Conveyed Perforating (TCP) was selected to carry out the operation, since static underbalance was necessary to monitor the response of the formation immediately after the perforating operation
- Workover campaign started in 2009, 8 wells completed during the first year, three of them have reliable build up information and will be discussed during this presentation

TCP Procedure

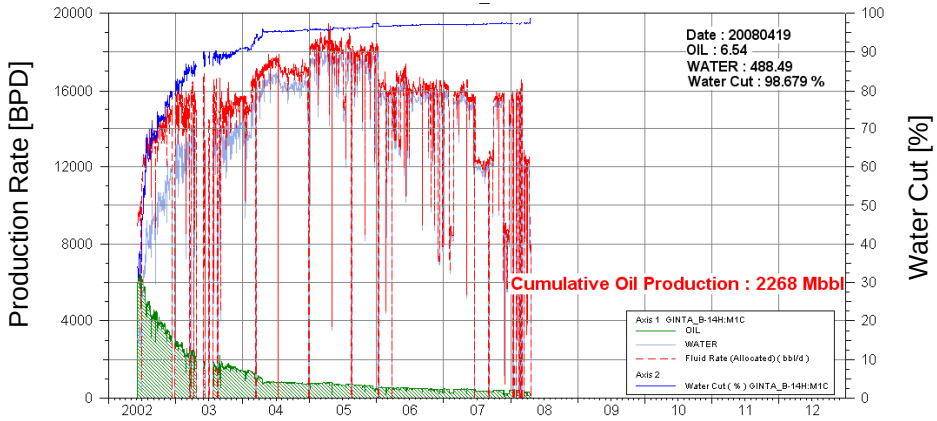
1. Bull Plug
2. 4 ½” DUB Guns: As specifically designed per well
3. Safety Spacer
4. Hydraulic Firing Head
5. Tubing
6. Flow Sub
7. Tubing
8. Mechanical Packer
9. Safety Joint
10. Hydraulic Jar
11. Fill Tester Valve (Open): Allows for communication from the annulus to the tubing to activate the hydraulic firing head
12. Pipe Tester Valve (Closed): Traps the fluid cushion in the tubing to create static underbalance
13. Collars
14. Radioactive Sub
15. Pipe to surface



Well A



- Drilled in 2001
- TD: 8,830 ft MD (7,595 ft TVD)
- M-1 sandstone opened for production: Horizontal Well



- Worked over in 2009 to change the production zone to Basal Tena (7,957' – 8,030')
  - Rock strength (UCS): 8,500 psi
  - Porosity: 20 %
  - Reservoir pressure: 2,000 psi
  - Formation damage: 20 in.
  - Oil gravity (density): 15° API
  - Permeability: 300 mD
  - Viscosity: 40 cp
  - Formation temperature: 200°F

Well A – Design and Execution

Perforating System Selection

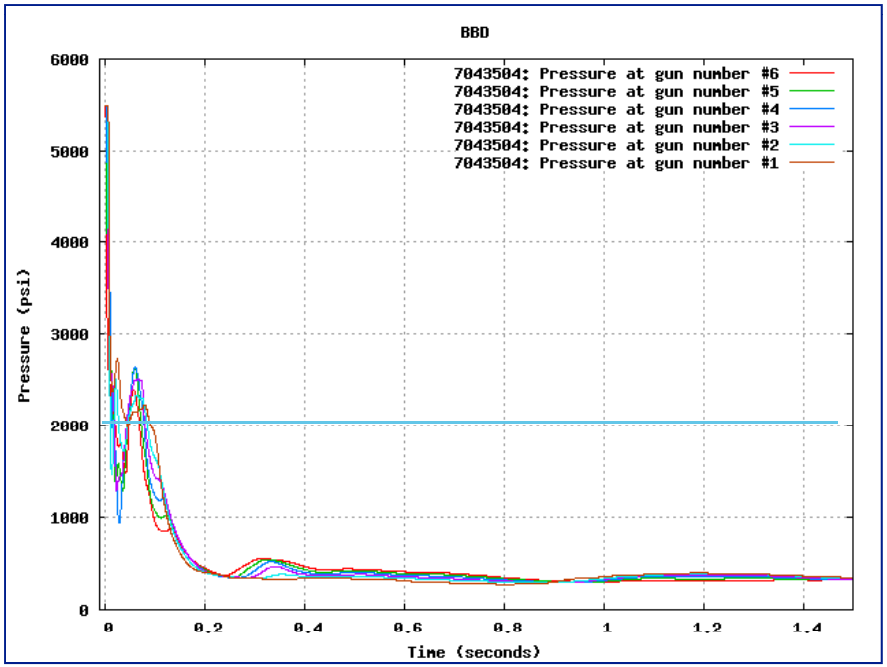
Parameter	System 1	System 2
Size	4 ½	4 ½
Charge Type	39-gr Ultra Deep	39-gr Ultra Deep
Shot density (spf)	4.75	5
DUB charges (spf)	0.25	0
Hydrostatic Pressure (psi)	5,500	800
Max DUB (psi)	-1,750	0
Rock Penetration (in)	25.9	25.9
Entrance Hole Dia. (in)	0.45	0.45
Productivity Ratio	1.18	1.01
Kc/K	0.91	0.1

Completion and Testing Phase:

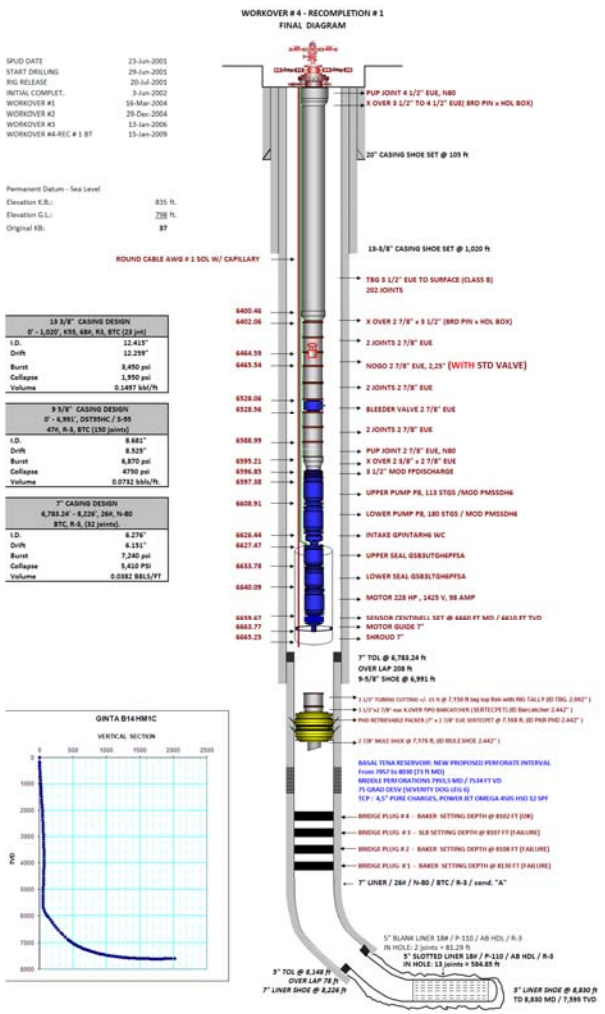
- TCP string recovery
- RIH ESP
- Clean-up period: 88 h @ 47 Hz
- Flow period: 22 d
- Shut-in period: 144 h

System 1 was chosen and executed as planned:

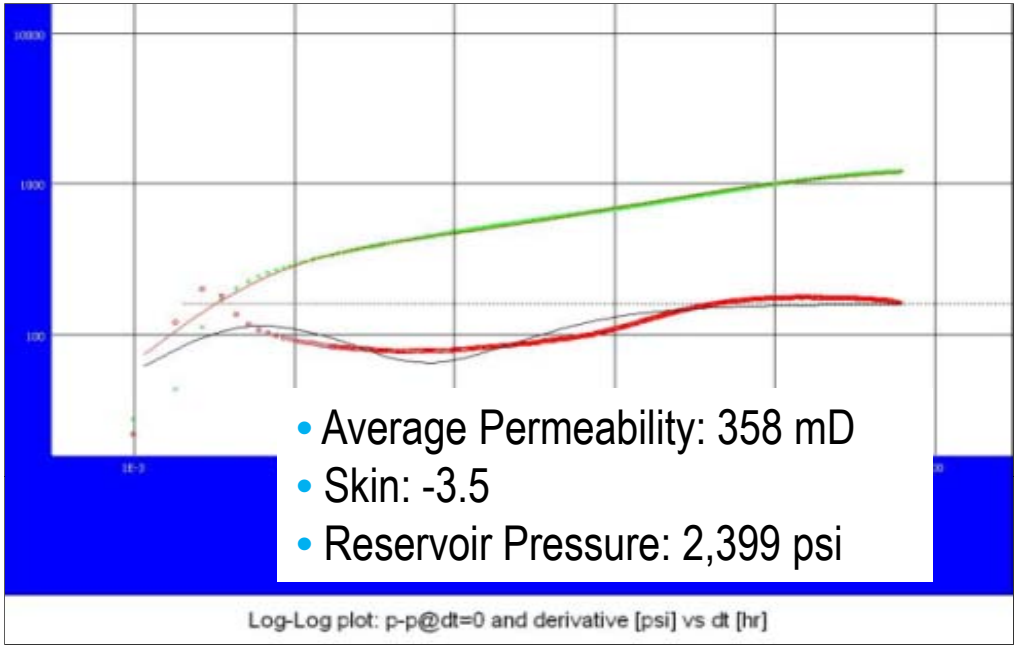
- Trapped pressure: 5,500 psi
- Expected dynamic underbalance: 1,750 psi
- Static underbalance: 1,200 psi upon activating the production valve to communicate rathole and tubing



Well A – Results

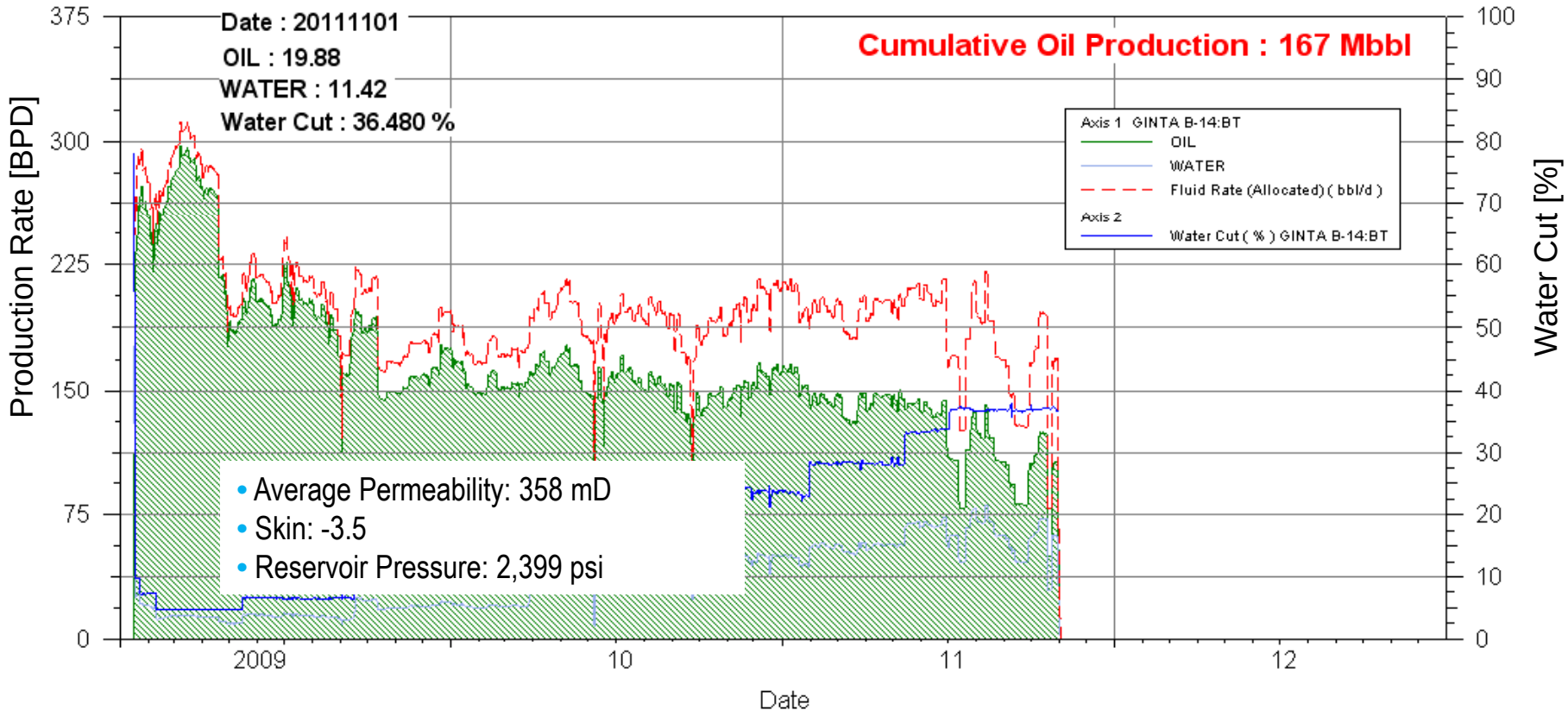


Pressure Build-up results:

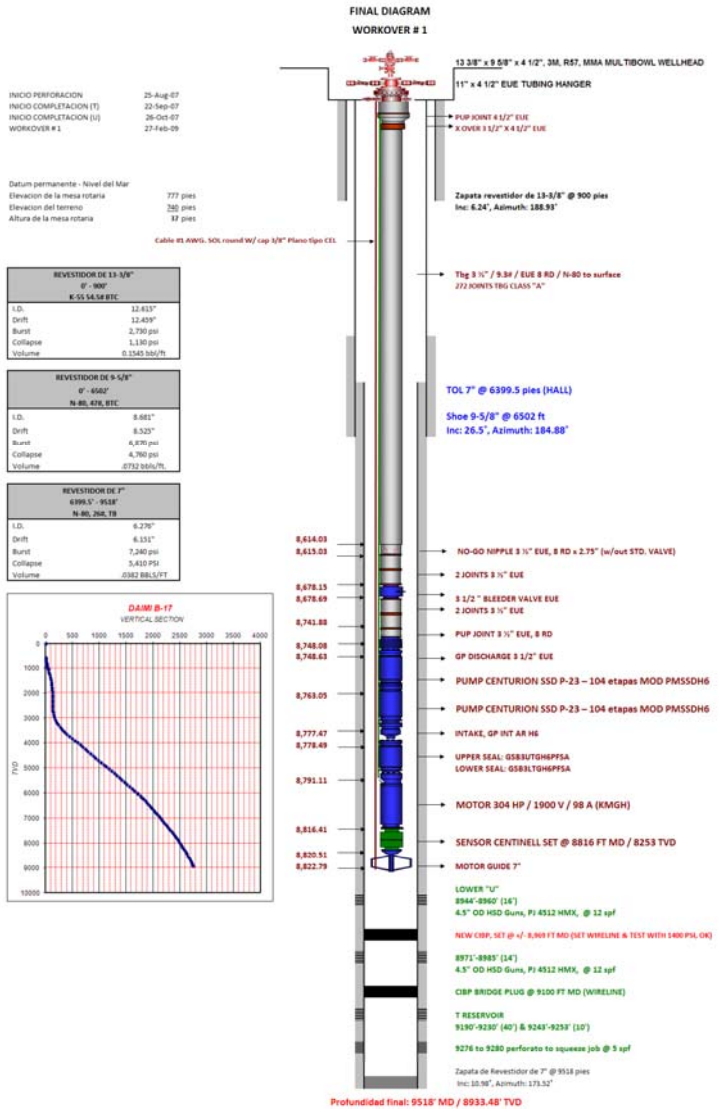


- Maximum production: 297 BOPD (BS&W: 2.8%) @ 49 Hz
- PI: 0.34 BFPD/psi
- Expected production: 200 BOPD
- Average production of 280 BOPD
- Incremental production: 40%

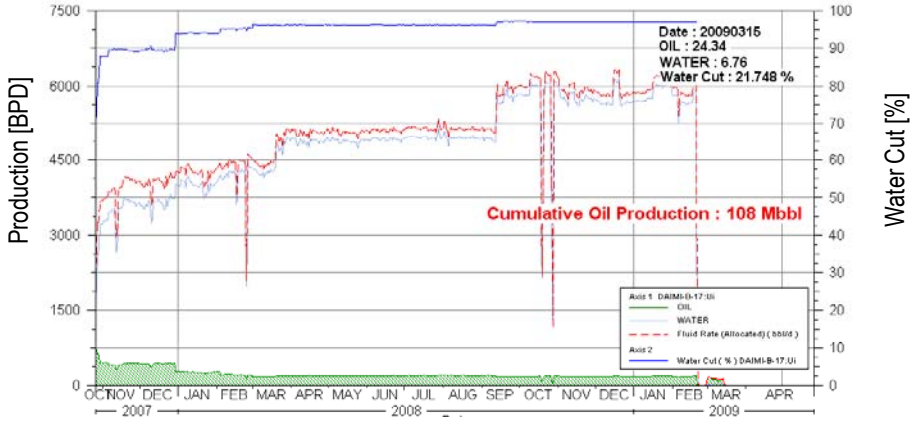
Well A – Results



Well B



- Drilled in 2007
- TD: 9,518 ft MD (8,933 ft TVD)
- T and Lower U opened for production



- Worked over in 2009 to change the production zone to Upper U (8,882' – 8,900')
  - Rock strength (UCS): 8,661 psi
  - Porosity: 18 %
  - Reservoir pressure: 3,330 psi
  - Formation damage: 15 in.
  - Oil gravity (density): 14.5° API
  - Permeability: 2,000 mD
  - Viscosity: 74.1 cp
  - Formation temperature: 215°F

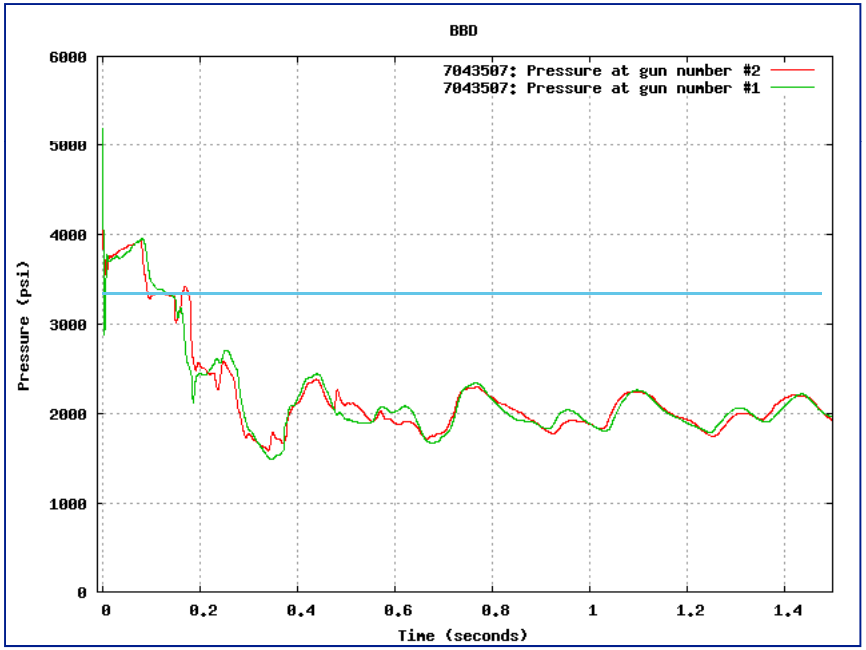
Well B – Design and Execution

Perforating System Selection

Parameter	System 1	System 2
Size	4 ½	4 ½
Charge Type	39-gr Ultra Deep	22-gr Ultra Deep
Shot density (spf)	4.75	11.75
DUB charges (spf)	0.25	0.25
Hydrostatic Pressure (psi)	5,200	8,500
Max DUB (psi)	-1,800	0
Rock Penetration (in)	25.5	16.6
Entrance Hole Dia. (in)	0.45	0.35
Productivity Ratio	1.22	1.17
Kc/K	0.99	0.93

System 1 was chosen and executed as planned:

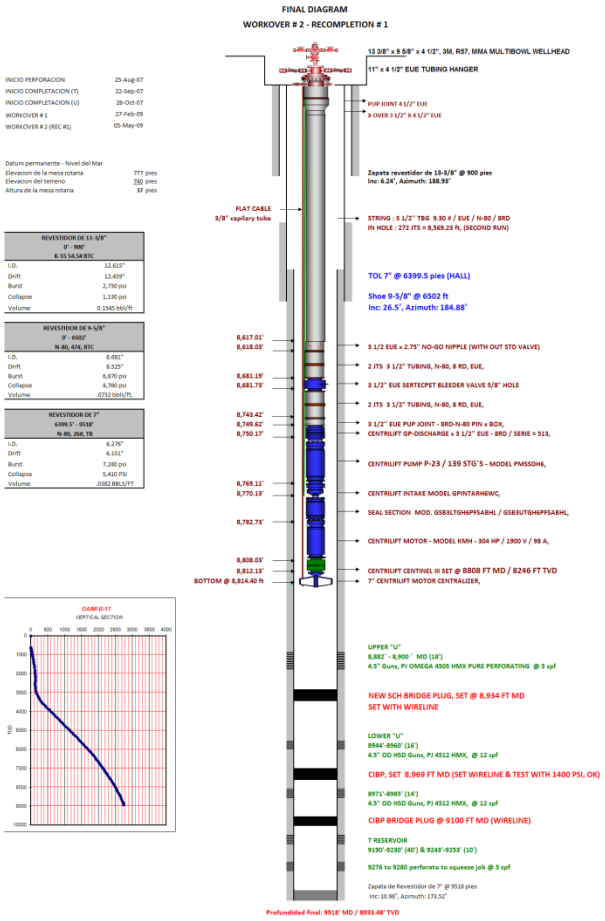
- Trapped pressure: 5,200 psi
- Expected dynamic underbalance: 1,800 psi
- Static underbalance: 1,500 psi



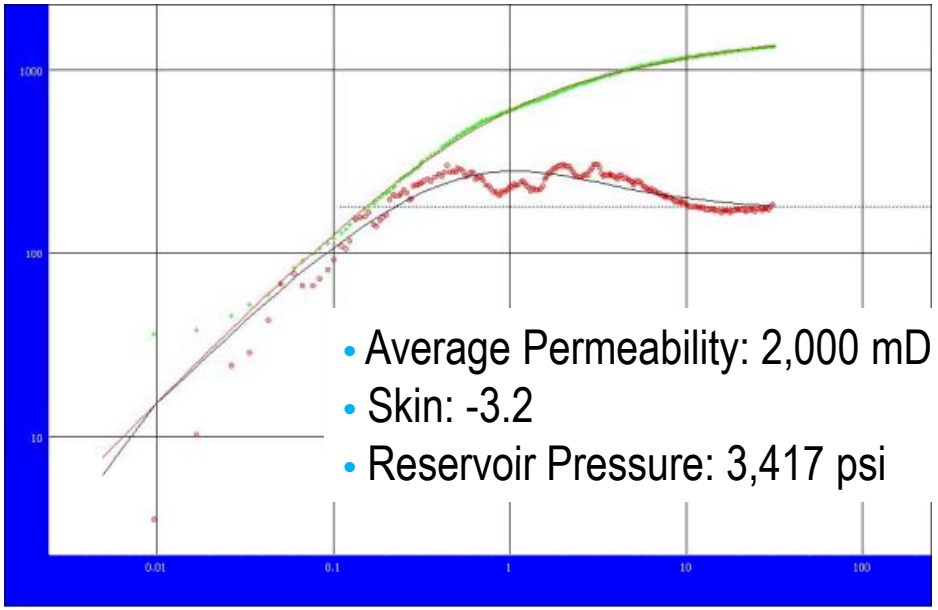
Completion and Testing Phase:

- TCP string recovery
- RIH ESP
- Clean-up period: 12 h @ 60 Hz
- Flow period: 19 d
- Shut-in period: 31.5 h

Well B – Results



Pressure Build-up results:

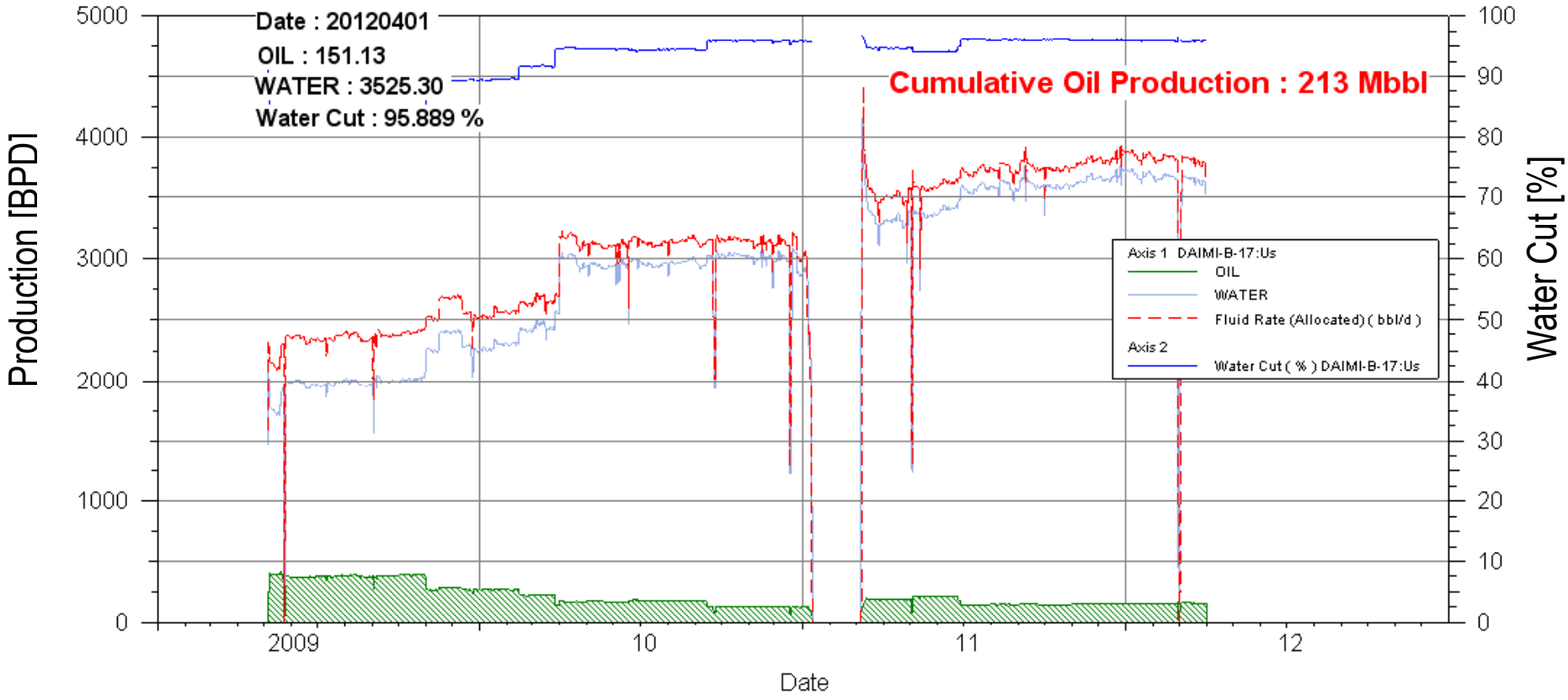


- Average Permeability: 2,000 mD
- Skin: -3.2
- Reservoir Pressure: 3,417 psi

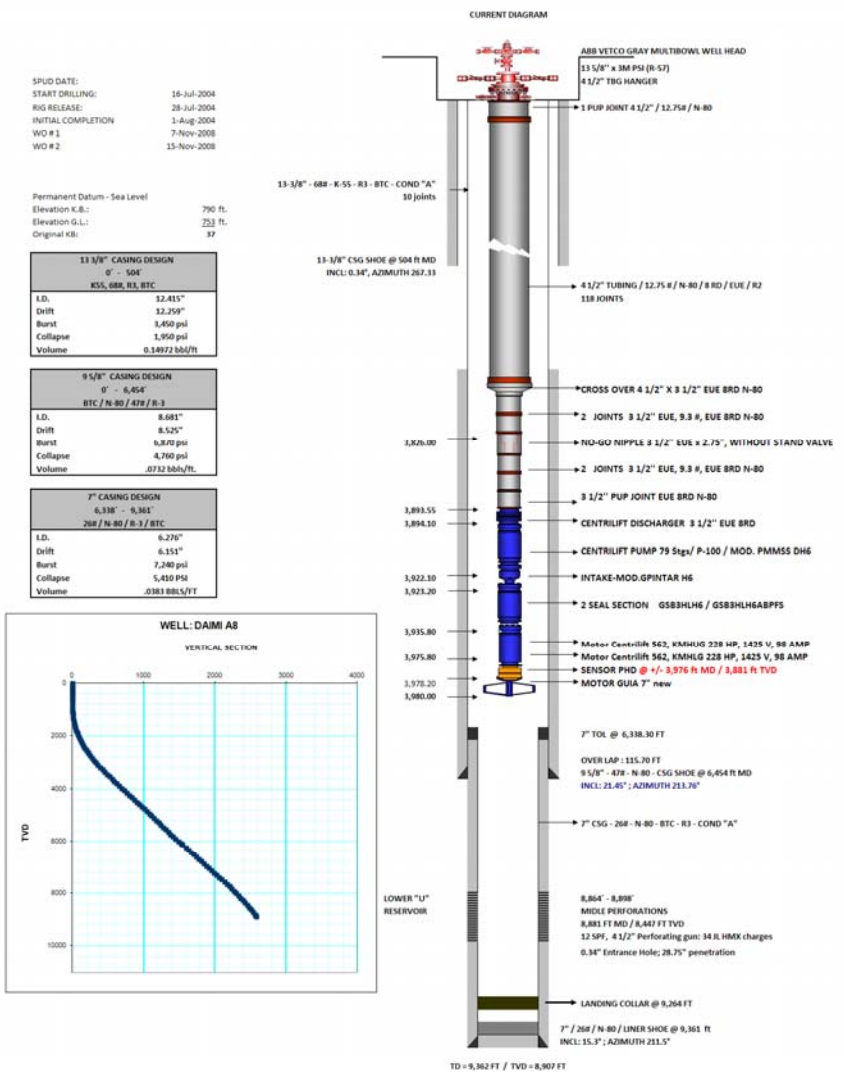
Log-Log plot: p-p@dt=0 and derivative [psi] vs dt [hr]

- Maximum production: 412 BOPD (BS&W: 71%) @ 49 Hz
- PI: 1.16 BFPD/psi
- Expected production: 300 BOPD
- Average production of 390 BOPD
- Incremental production: 30%

Well B – Results

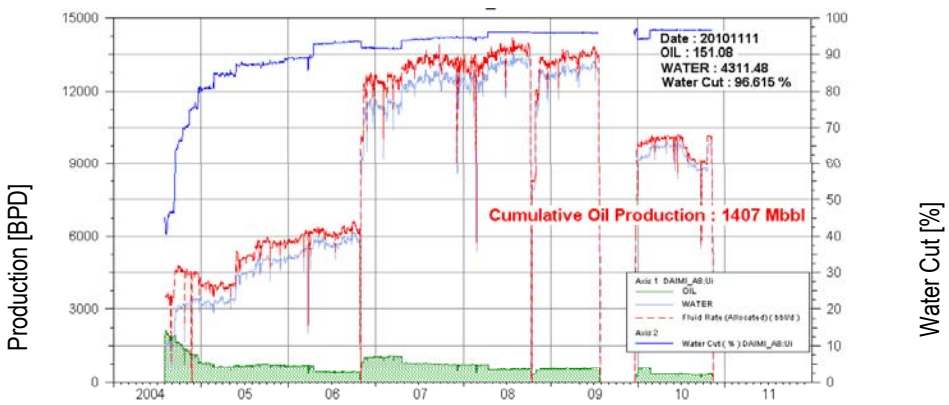


Well C



- Drilled in 2004
- TD: 9,362 ft MD (8,907 ft TVD)

Lower U sandstone opened for production



Worked over in 2008 to change the production zone to Upper U (8,788' – 8,800')

- Rock strength (UCS): 5,358 psi
- Porosity: 21 %
- Reservoir pressure: 3,330 psi
- Formation damage: 6 in.
- Oil gravity (density): 14.5° API
- Permeability: 2,200 mD
- Viscosity: 74.1 cp
- Formation temperature: 214°F

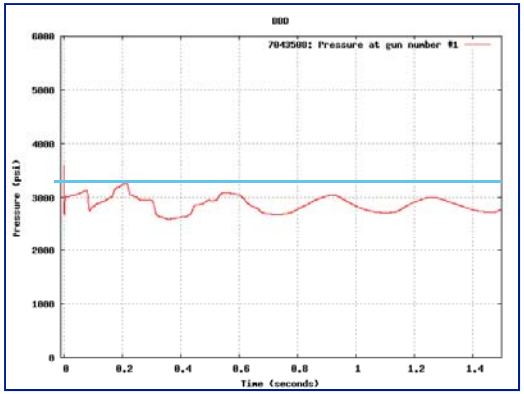
Well C – Design and Execution

Perforating System Selection

Parameter	System 1	System 2	System 3	System 4	System 5	System 6
Size	4 ½	4 ½	4 ½	4 ½	4 ½	4 ½
Charge Type	22-gr STD	22-gr Ultra Deep	22-gr Ultra Deep	39-gr STD	39-gr Ultra Deep	39-gr Ultra Deep
Shot density (spf)	12	12	11.75	5	5	4.75
DUB charges (spf)	0	0	0.25	0	0	0.25
Hydrostatic Pressure (psi)	2,330	2,330	5,600	2,330	2,330	3,600
Max DUB (psi)	0	0	0	0	0	1,000
Rock Penetration (in)	15	16.6	16.6	21.4	25.5	25.5
Entrance Hole Dia. (in)	0.32	0.35	0.35	0.49	0.45	0.45
Productivity Ratio	1.32	1.35	1.37	1.28	1.35	1.43
Kc/K	0.52	0.45	0.93	0.18	0.21	1

System 6 was chosen and executed as planned:

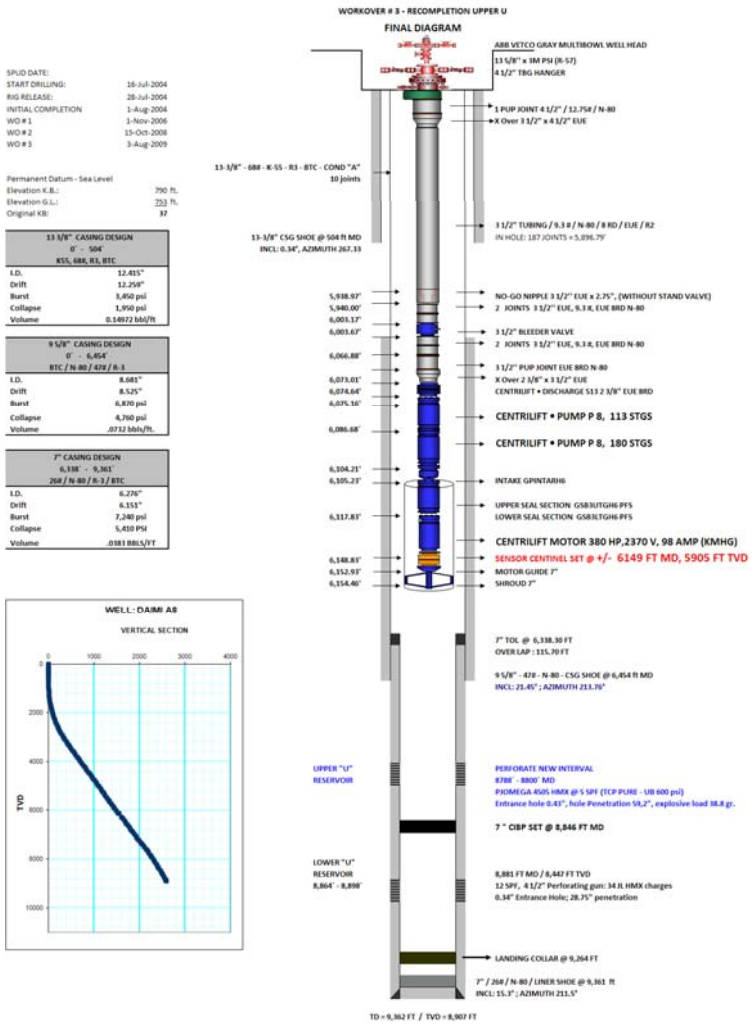
- Trapped pressure: 3,600 psi
- Expected dynamic underbalance: 1,000 psi
- Static underbalance: 1,000 psi



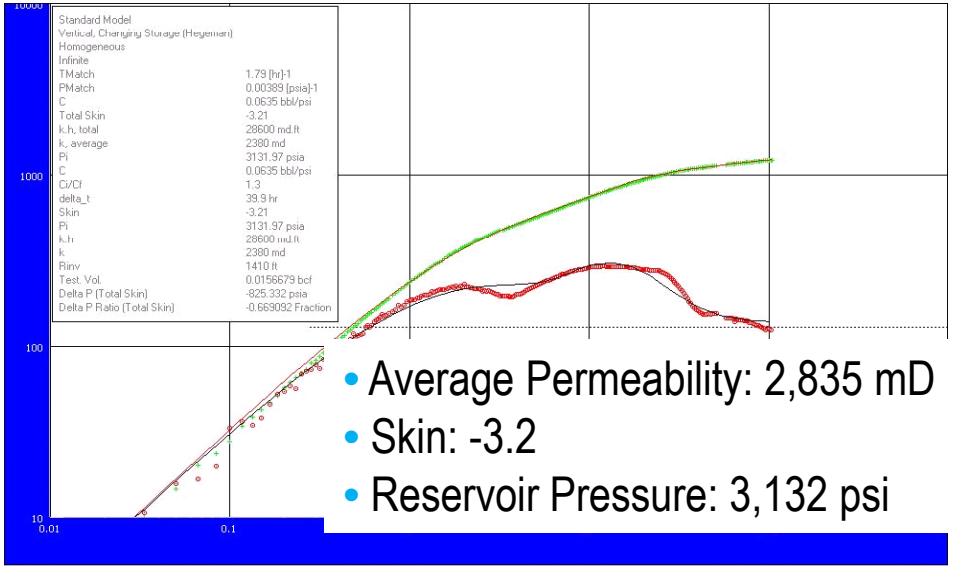
Completion and Testing Phase:

- TCP string recovery
- RIH ESP
- Clean-up period: 23 h @ 50 Hz
- Flow period: 21 d
- Shut-in period: 100 h

Well C – Results



Pressure Build-up results:

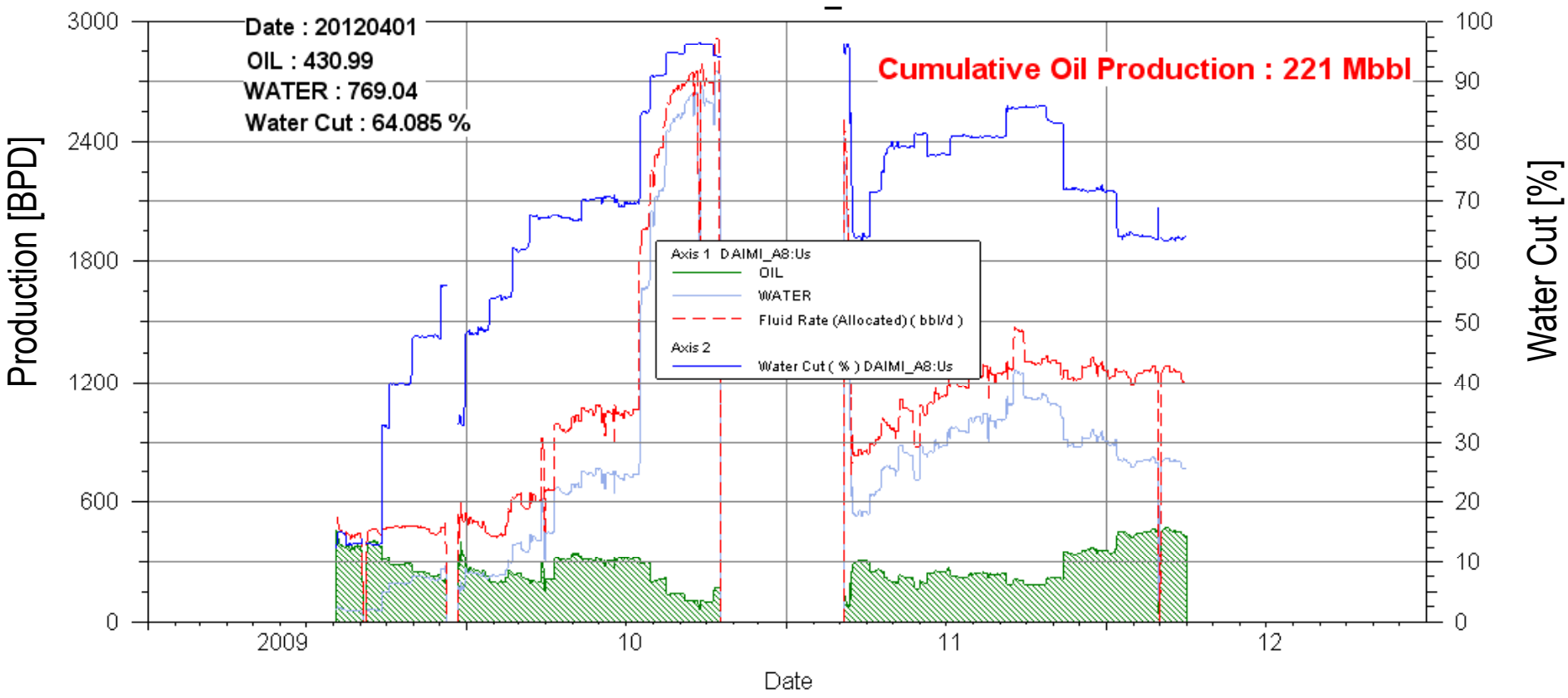


- Average Permeability: 2,835 mD
- Skin: -3.2
- Reservoir Pressure: 3,132 psi

Log-Log plot: p-p@dt=0 and derivative [psi] vs dt [hr]

- Maximum production: 470 BOPD (BS&W: 8.5%) @ 50 Hz
- PI: 0.44 BFPD/psi
- Expected production: 250 BOPD
- Average production of 380 BOPD
- Incremental production: 52%

Well C – Results



Summary and Conclusions

- The combination of Ultra-deep-penetration charges with Dynamic and Static underbalance conveyed on pipe optimized the perforating process inside Repsol's fields in Ecuador
- Build-up tests showed negative skin, which was achieved by connecting to the virgin zone with clean perforation tunnels. These results were compared with other wells perforated using conventional technology and most of them have positive skin, therefore the perforating process was optimized
- The DUB technique has increased productivity in the Basal Tena and Upper U reservoirs in Block 16 mature fields, as a result of production improvement DUB technique was recommended and implemented for future jobs