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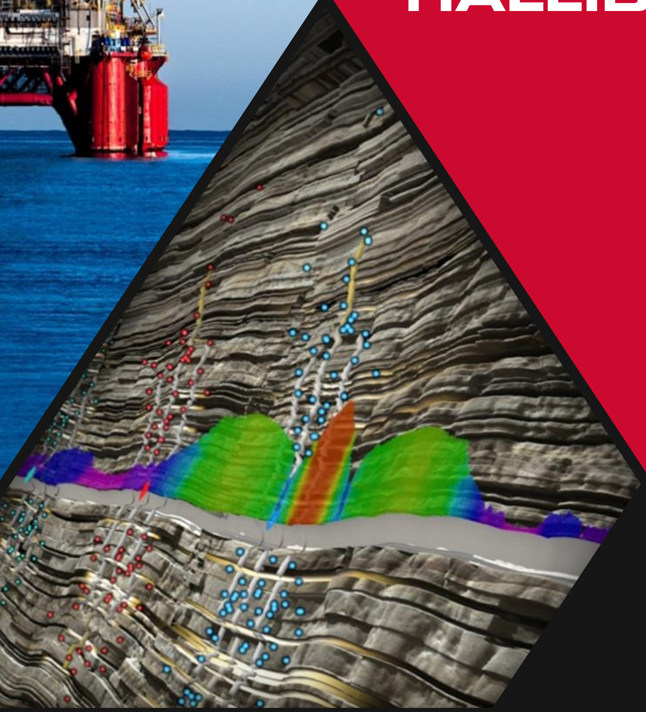

Drilling ECD Control: Reduce Risk, Uncertainty and Operator NPT

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AADE
AMERICAN ASSOCIATION of DRILLING ENGINEERS
HOUSTON CHAPTER
"The Industry forum for Drilling practices and technology"

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FLUIDS MANAGEMENT GROUP

Solving challenges.™

Agenda

- What is ECD?
- How can we manage the ECD?
  - Define the window
  - Strategy:
    - Apply fit-for-purpose fluids
    - Monitor pressures and drill accordingly
    - Review results
- Case Studies (5)
  - Mature field
  - Deepwater
- Questions

Pushing the Red Line
Image from Run on Purpose, www.runonpurpose.com

What is ECD?

- It is like the blood pressure of your well-
  - For people it should stay around 120/80 mmHg
  - Cats are up at 180/135
  - Pressure is seldom too low, and if it is you have some other serious issues
  - Medicines typically reduce the amount of fluid in the bloodstream, or act to widen and relax blood vessels; reducing the pressure

- For drilling, every well is different
  - We have to focus more on the fluid design and the pressures acting on the system

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What is ECD?

- ECD is the fluid density plus annular pressure loss

$$ECD = \left[\frac{APL}{(0.052 \times TVD)}\right] + MW$$

- Factors affecting the total APL:

Drilling Variable	Effect of Increasing the Variable
Flow rate	Increase
Section length	Increase
Hole size	Decrease
Drillstring diameter	Increase
ROP	Increase

Fluid Variable	Effect of Increasing the Variable
Plastic viscosity	Increase
n	Increase
K	Increase

Define the Pressure Window – How Narrow?

- How do we find it?
  - Formation Analysis
  - Simulation Software
    - Well trajectory
    - Wellbore geomechanics
  - Offset well data
    - FIT and recorded pressure/losses
    - PWD trace
- Still not a precise number, and exploration work is much more variable

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Pressure Window Strategy – Wide to Narrow

	Margin between minimum-FIP and ESD	***Greater than 1.2 lb/gal****	***From 0.6 to 1.2 lb/gal****	***Less than 0.6 lb/gal****
	Circulating Mode	**Conventional**	**Controlled Pressure**	**Managed Pressure**
Design elements	**Drilling hydraulics**	Hydraulics simulators may be needed	Accurate planning and tracking very helpful	Accurate planning and tracking critical to success
	Drillstring geometry	BHA design and DP size are not concerns	BHA & DP w/minimal passing OD for expected loads, watch tool joints	BHA, DP and tool joints w/minimal OD, limit near-gauge stabilizers
	Pressure tools	PWD sub may not be needed	Accurate sub required at all times	Accurate PWD, consider equipping w/MPD head
	Fluid specifications	Conventional fluids; YP of 20-35	Low-ECD fluids, controlled rheology with YP of 12-18, PV ALAP, 6/3-rpm AHAP	Specialized low-ECD fluids with even lower rheology, plus LCM for stress fracture sealing
	Drilling practices	Standard tripping practices, pipe speeds not a big concern	Slower trips, may pump OOH & need to optimize running speeds	Density changes required for POOH, slower trips, might need to pump OOH

*This still depends greatly on the hole size and other factors

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Fit for Purpose Fluids

More Challenging Wells

Standard IEF

Technical Challenges
Wide ECD Windows
Sag Potential: Medium
Gel structure: Variable

Capability Ranges
Temperature: 100-475°F
Density: 9-18 ppg

Fluid Characteristics
Consistent properties at high temperatures & density; organoclays and organolignite control major functions, cold temperatures make them very thick, mud losses can be high

Advanced IEF

Technical Challenges
Intermediate ECD Windows
Sag Potential: Lower
Gel Structure: Variable

Capability Ranges
Temperature: 40-400°F
Density: 9-18 ppg

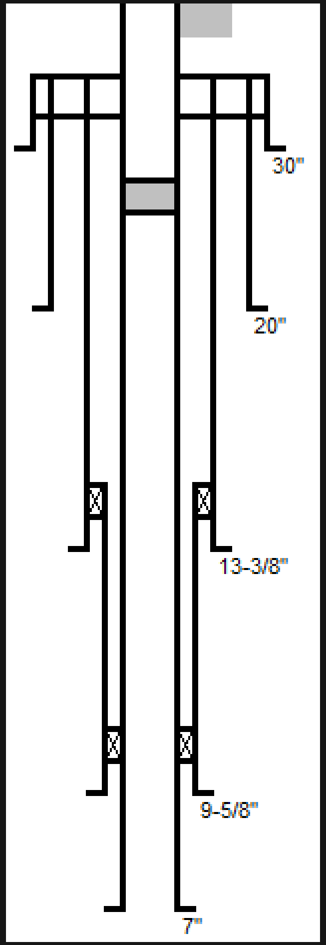
Fluid Characteristics
Stable rheology across a wide temperature range; lower organoclay content and most use small amounts of polymers for filtration control, losses are often reduced and the ECD is somewhat lower

Low-ECD IEF

Technical Challenges
Narrow ECD Windows
Sag Potential: Minimal to nil
Gel Structure: Variable

Capability Ranges
Temperature: 40-375°F
Density: 10-18 ppg

Fluid Characteristics
Stable rheology across wide temperature range; similar formulas to Advanced; rheology/ECD is much lower (approx. 1 lb/gal under Standard), and micron-sized weight materials are often used



Fit for Purpose Fluids

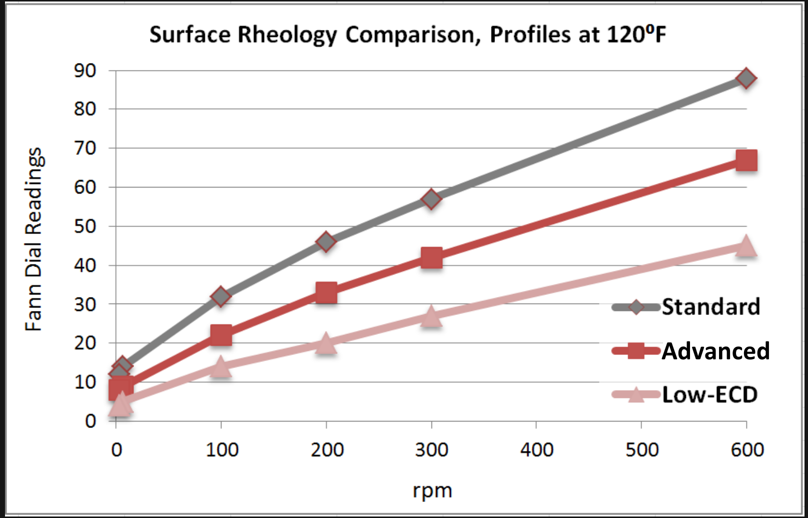
How does the Industry Describe them?

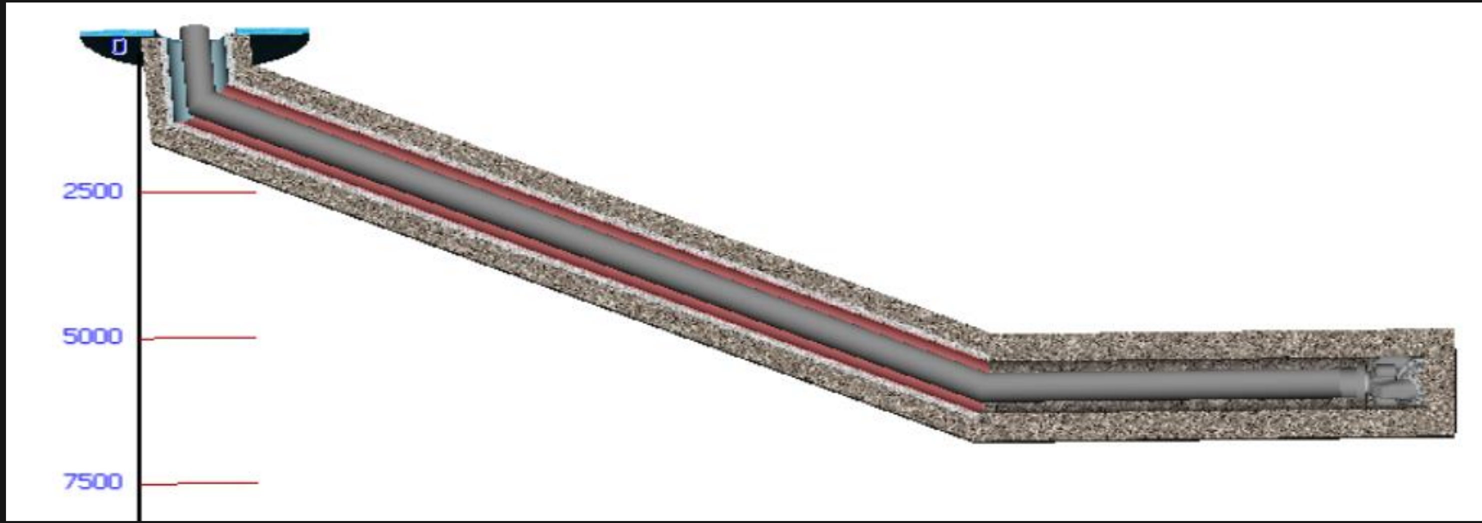
- “Low ECD”?
- “Flat Rheology”?
- “Fragile Gel”?
- “High-Performance”?

Fit for Purpose Fluids

"Low ECD"

- Defined as: lower than some other fluids in the market
- This depends greatly on the application





Modeling Results – 21,000' MD Well/9" Lateral, Nominal 12 lb/gal Surface Density

1. ECD was **+2.2 lb/gal** with Standard IEF
2. Reduced by <u>0.6 lb/gal</u> using Baroid Advanced system
3. Reduced further to <u>1.0 lb/gal</u> less using Baroid Low-ECD fluid (with adequate hole cleaning in laminar)

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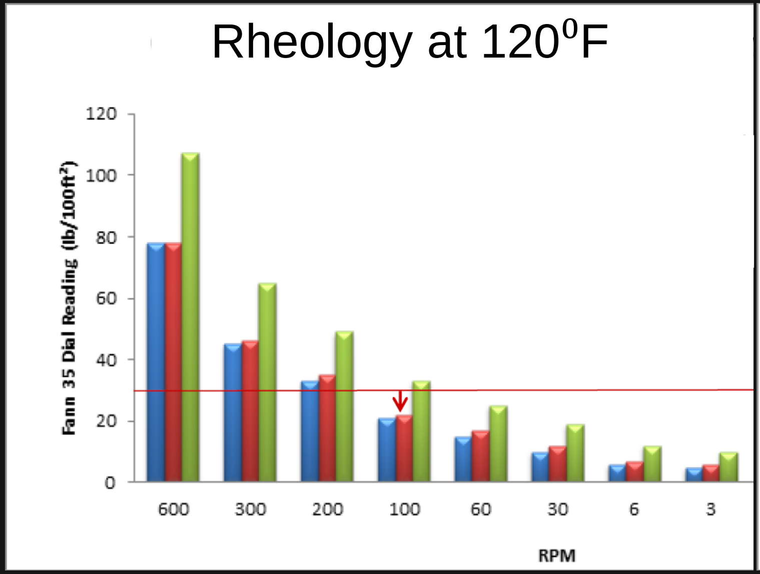
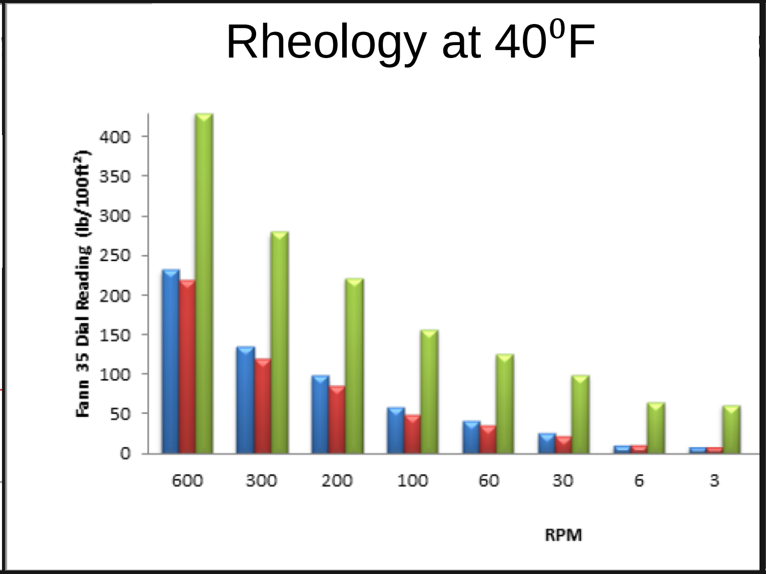
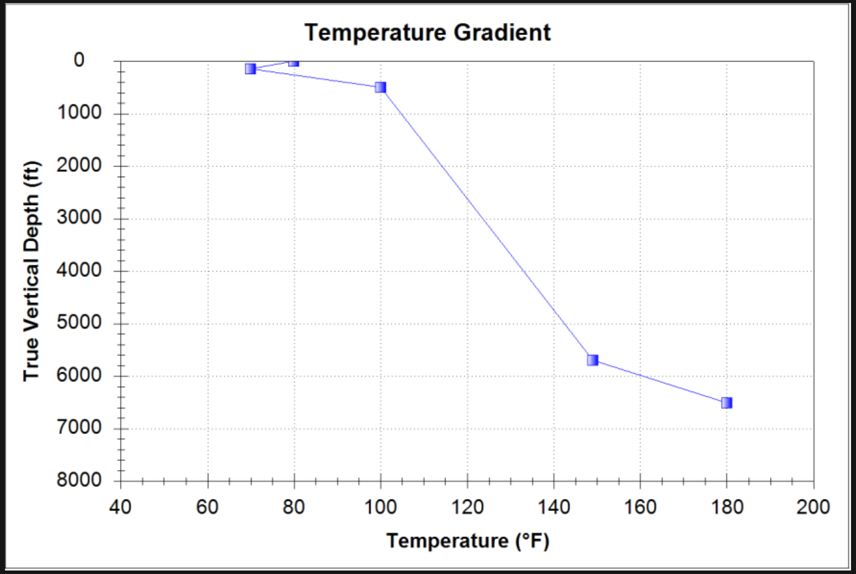
Fit for Purpose Fluids

“Flat Rheology”

- Defined as ‘not much’ change from cold temps to highest temps in well
- Often measured by 40ºF, 80ºF 120ºF/150ºF surface rheology







Green = Baroid Standard fluid, Red/Blue = Baroid Low-ECD fluids

Is Flat Rheology Needed Here?

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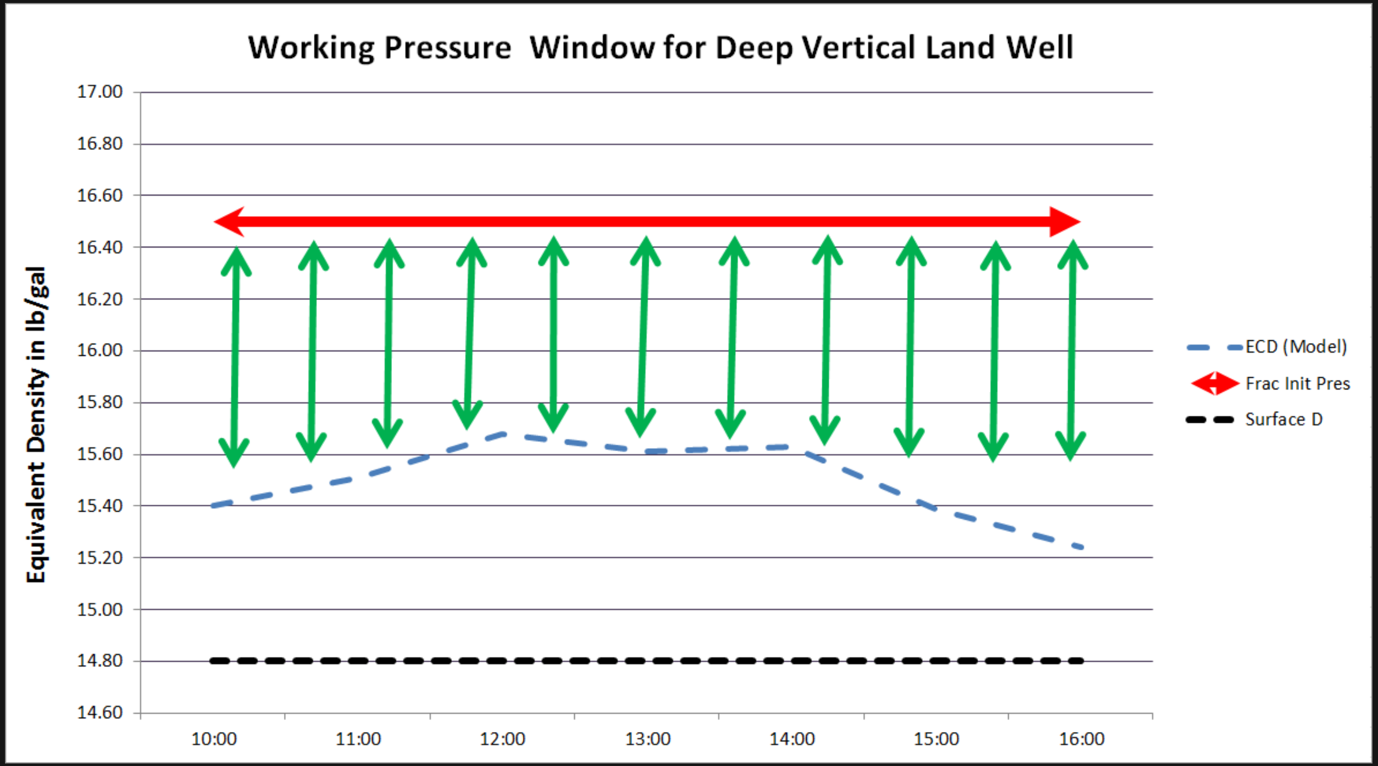
Fit for Purpose Fluids

“Fragile Gel”

- Defined as a fluid with gels which build rapidly and aid in suspension character at low shear rates, and yet dissipate easily when shear rates increase - to leave no trace of pressure spikes on downhole sensors. *This is somewhat independent of rheology*.
- What do we expect from a Fragile gel versus a regular gel?
  - Lower initiation pressure
  - Less energy needed to break it
  - Lower surge/swab
- **This is often more important in narrow pressure margin wells than ‘flat rheology’**
- Gels also enhance hole cleaning
- What about fluids with no gels?
  - Advantages - Less Pressure
  - Disadvantages - Less Suspension of barite/LCM/cuttings, poorer hole cleaning, if built with small particle weighting agents, probably cannot use regular weight material in an emergency

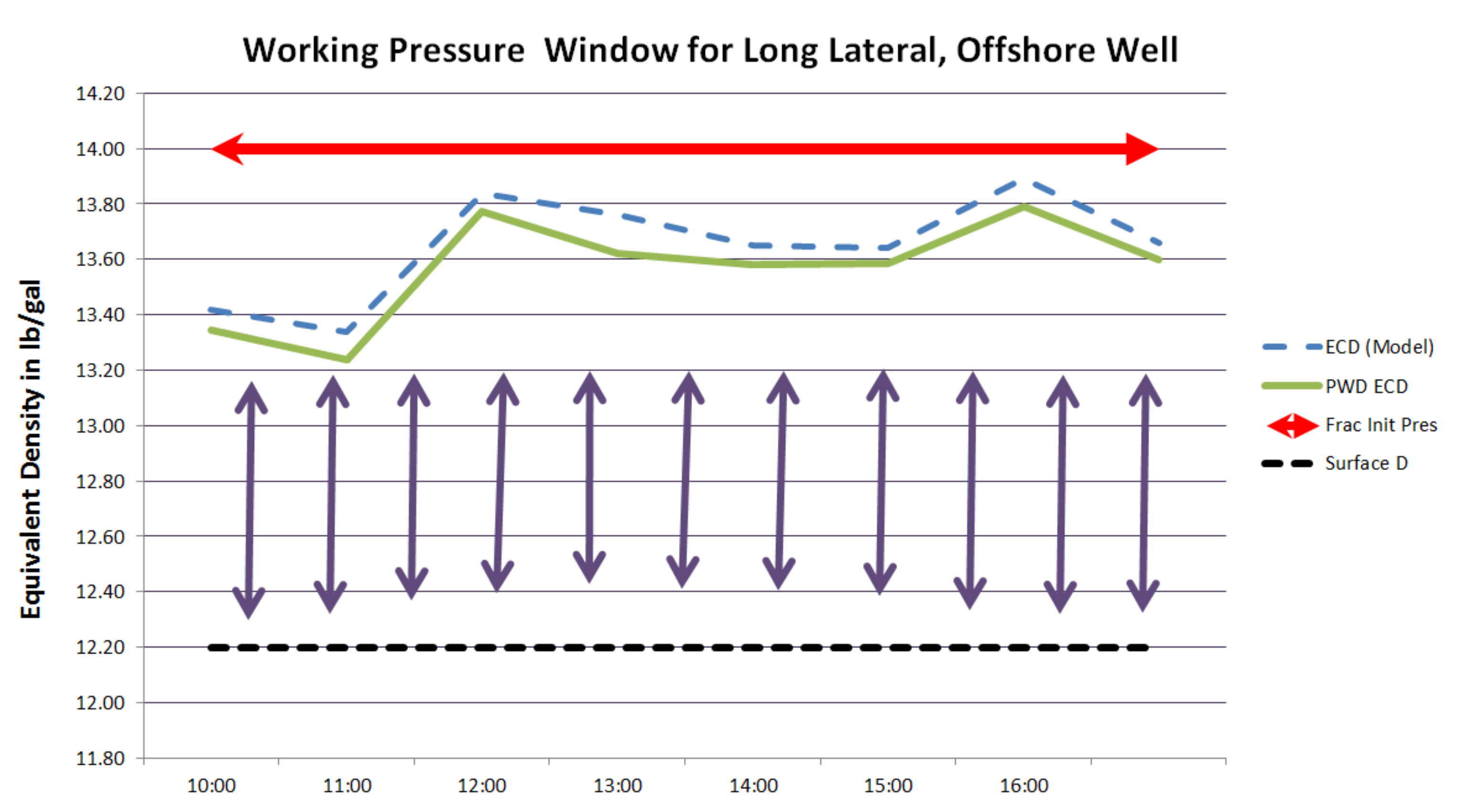
Monitoring Pressures - PWD 1

- In this example we see the zone of opportunity
  - When the fluid delivers at the expected ECD (or lower!) you can often increase ROP
  - Drilling parameters may require adjustments due to emerging changes



Monitoring Pressures - PWD 2

- Long laterals with depleted reservoirs make for even tighter windows
- A conservative hydraulics model helps to avoid surprises, Real-Time is even better



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Case Studies – Mature Fields

- Cases #1-4: Several ERD wells in depleted reservoir
    - Density near 12 lb/gal with FG of approx. 13.5
    - ECD near FG for entire interval (within 0.5 lb/gal)
  - First well – ECD was higher than predicted by 0.5 lb/gal; causes were:
    - Near-gauge stabilizers and **tool joints** not accurately accounted for
    - Fluid rheology started higher than planned due to water picked up in transfer
  - Second well – ECD higher than the first; due to 5.5-in DP (temporary rig)
  - Third well – Drilled to TD successfully, but swab on trip out contributed to wellbore instability
    - Difficulty running liner, did not reach TD
  - Fourth well – <u>Successfully managed ECD safely and ran the deepest liner in the field</u>
    - Drilling practices and fluids management had improved
    - ECD modeling and PWD tracking (matched most of well) helped to verify proper hole cleaning

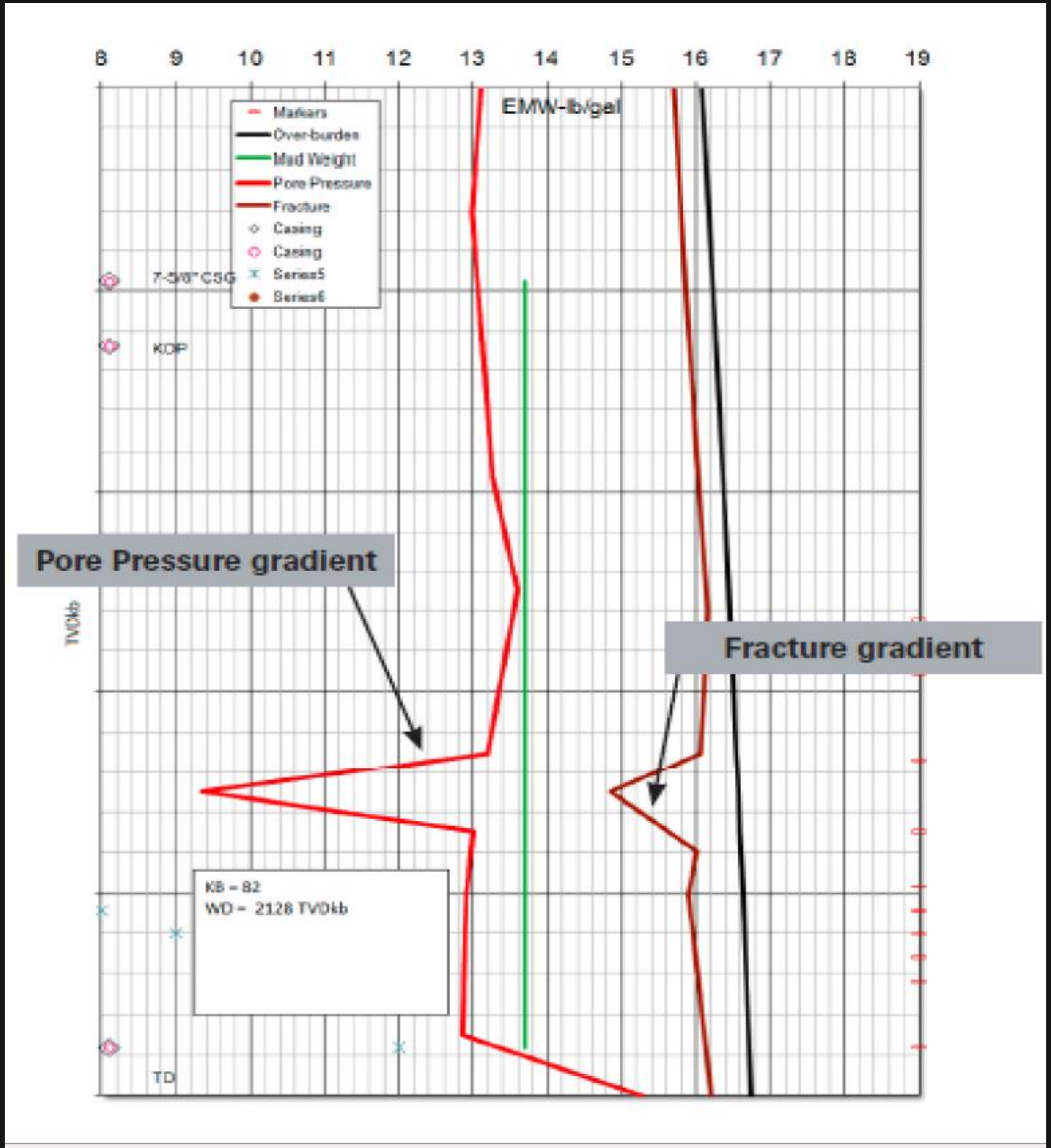
Case Histories – Overview of Deepwater GOM

- Conditions require “Flat Rheology” and Fragile Gel character
- In large hole sizes ECD is much less a concern
- At 12 ¼” and smaller it becomes more critical-
  - Multiple wells dealing with <0.5 lb/gal windows
  - One well at 0.5 lb/gal window, all sections
  - 0.2 lb/gal window was one of the lowest
- Background LCM or wellbore strengthening material is often used
  - *Must lower the ECD* to accommodate this 0.2-0.3 lb/gal increase

- Successes:
  - 18 wells drilled with no indications of barite sag or stuck pipe while drilling, tripping, logging and running casing. ECDs within the safe operating window and successfully reaching TD.
  - Customer A: Ran the production liner with 100% returns and the cement with 90% returns, eliminating the need for a liner top squeeze like on offsets. Savings of approx. $1,000,000 over past wells
  - Customers A-F: Savings in valuable rig time

Deepwater S/T Well

- 7.5 inch hole
- 64 degree angle
- 13.7 ppg surface mud weight
- 14.8 ppg frac-gradient in the "Sand"
- Sand depleted to 9.3 ppg EMW
- 15.0 ppg FIT



ECD Performance of Low-ECD Technology in Deepwater S/T Well

- Hydraulics modeling from Deepwater S/T using Low-ECD Technology showed a 0.47 ppg reduction in ECD compared to the SBM field fluid modeled for Deepwater S/T

Deepwater S/T Regular SBM 13.7 ppg

DrillAhead Optimization			
ECD vs ROP vs Pump Rate			
Pump Rate	220.0 gal/min	230.0 gal/min	240.0 gal/min
ECD	lb/gal	lb/gal	lb/gal
ROP ft/hr			
20	15.118	15.153	15.187
30	15.143	15.176	15.209
40	15.169	15.201	15.233
50	15.194	15.225	15.256
60	15.216	15.245	15.28

Deepwater S/T Formulation Low-ECD SBM 13.7 ppg

DrillAhead Optimization			
ECD vs ROP vs Pump Rate			
Pump Rate	220.0 gal/min	230.0 gal/min	240.0 gal/min
ECD	lb/gal	lb/gal	lb/gal
ROP ft/hr			
20	14.623	14.641	14.659
30	14.662	14.679	14.694
40	14.698	14.712	14.73
50	14.737	14.749	14.761
60	14.771	14.78	14.796

*Modeling parameters used were the same with the exception of the fluids and their corresponding properties

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Deepwater S/T Well - Actual Drilling Parameters

Baroid Hydraulic Model vs PWD

DrillAhead Optimization		
ECD vs ROP vs Pump Rate		
	DFG Predicted	PWD Actual
Pump Rate	220 gpm	220 gpm
ECD	lb/gal	lb/gal
40 ft/hr	14.698	14.65
Variance	0.05 ppg	

- Pump Rate: 220 gpm
- ROP: 40 to 60 ft/hr
- RPM:120
- Average PWD ECD: 14.65 ppg*

*DFG has a conservative margin built in and typically runs slightly higher than PWD + 0.1 ppg

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Deepwater S/T Well - Fluid Properties Summary

- Stable, very predictable rheological properties
- 6 and 3 RPM readings in excellent range for hole cleaning for given wellbore
- Rheology adjustable using additive package based on ECD requirements

Mud Report	600	6	3	PV	YP	10Sec	10Min	30Min
11/24/2011	63	8	7	24	15	10	19	23
11/25/2011	63	8	7	24	15	10	19	23
11/26/2011	64	8	7	24	16	12	19	21
11/27/2011	63	8	7	24	15	11	19	21
11/28/2011	59	8	7	22	15	10	21	22
11/29/2011	58	8	7	21	16	11	20	21
11/30/2011	60	8	7	22	16	11	21	23
12/1/2011	55	8	7	19	17	11	21	23
12/2/2011	56	8	7	20	16	11	17	21
12/3/2011	59	9	7	21	17	11	21	23
12/4/2011	60	9	8	22	16	11	21	23
12/5/2011	59	9	8	21	17	11	21	23
12/6/2011	60	9	8	22	16	12	23	25
12/7/2011	59	8	7	22	15	11	21	23
12/8/2011	61	8	7	22	17	11	21	23
12/9/2011	61	8	7	22	17	11	21	23
12/10/2011	61	8	7	22	17	11	21	23
12/11/2011	61	8	7	22	17	11	21	23

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Drilling ECD Control - Summary

- Special Fluids benefit conventional and MPD cases
  - Low-ECD, Fragile Gel, Flat Rheology(deepwater)
  - Understand their benefits/limitations
- Drilling engineering and practices must also adapt
- Accurate Hydraulics Software plays a key role
  - Planning
  - Real-Time Monitoring (weather forecast)
- Link models to PWD monitoring to plan, predict, optimize and help avoid train wrecks
- Small windows can hold great opportunities

Questions?