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A DECADE OF FORMATION TESTING, DO'S AND DON'TS AND TRICKS OF THE TRADE

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Presentation Outline

- Review Status of Technology Today
- Pitfalls of planning
- Acquisition tricks
- Pitfalls of Interpretation
- Conclusions

Sampling & Testing Status a Decade Later

- Pump-out generation of WFT's revolutionized sampling,
- Representative samples successfully achieved,
- WFT samples form basis for development design,
- Pressures measurements are taken for granted,
 - Refinements are needed,
 - Uncertainty models to include positioning and gauge errors,
- Only intimate involvement of the oil companies can lead to successful results.
 - These logs can not be played back nor recomputed.

Model of Operation

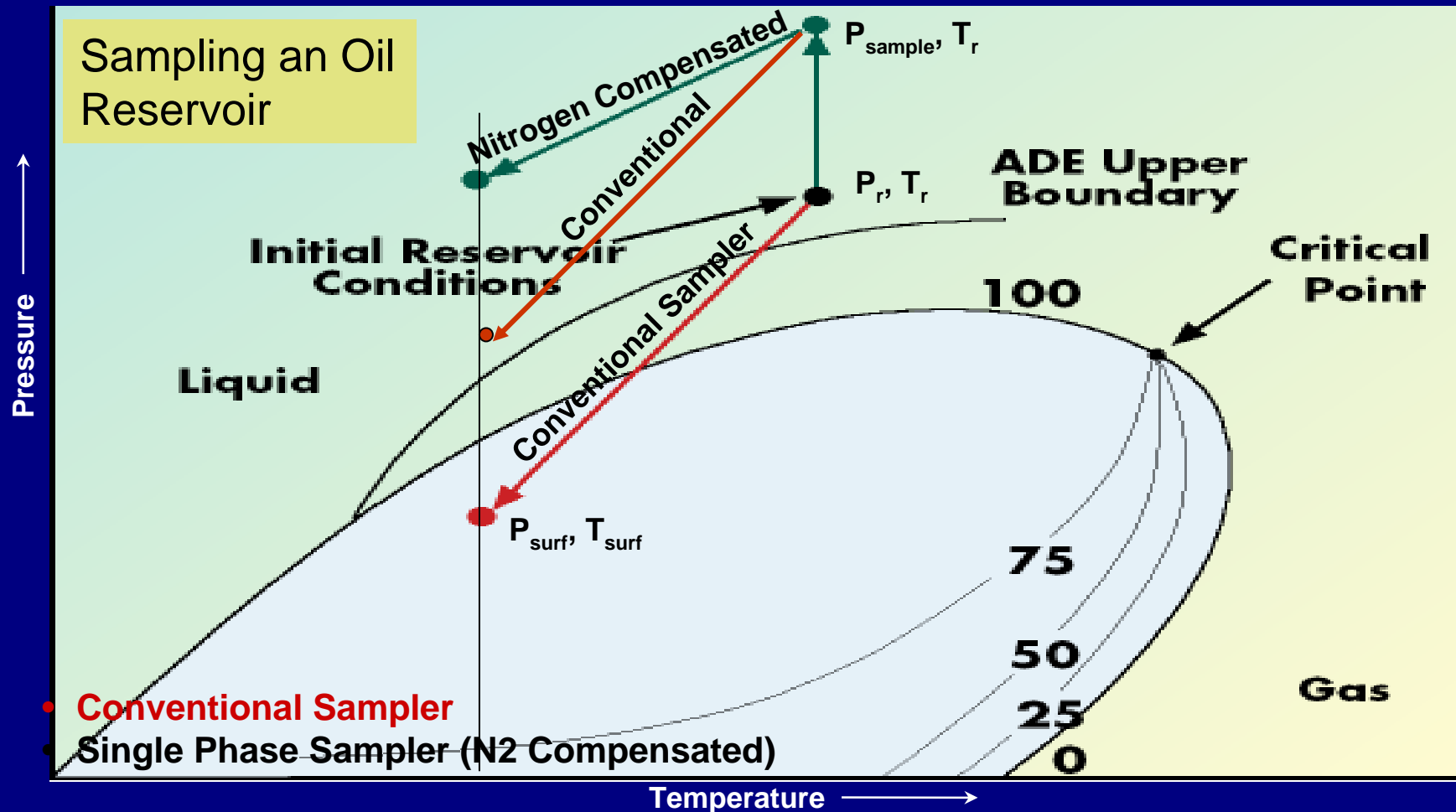
- Sampling & testing operation considered crucial,
 - very commonly run first in the well in critical cases.
- Do what it takes to get the correct answers;
 - time, volume, validation, tool string, resources & involvement.
- Assembled a team of fluid experts (FEAST) to advise on life cycle of reservoir fluids and their impact
 - Petrophysics, PVT, Reservoir, Geochemists,
 - Flow assurance, Basin Modelers, etc.,.

Fluid Evaluation And Sampling Technology (FEAST) Concept

- Acquire high quality pressure, permeability and fluid samples through down-hole instruments
- QC of data and service providers techniques.
- Development and implementation of related technologies.
- One Stop Shop! available to the asset teams.
 - all you need to know and do with your fluids for planning, acquisition and interpretation
- Future field development planning;
 - fluids compatibility, commingling strategies, connectivity,
 - production problems mitigation, special studies.

Planning

Possible Alterations to the Sample While Tripping out of Hole



How Much Pressure Drop Due to Cooling?

$$\square \Delta P = (\alpha / c_o) \Delta T$$

- Where:

- $\square \Delta P$ = Downhole closing Press – Surface opening press

- $\square \alpha$ = Thermal expansion coef of sample fluid, $\sim 5 \times 10^{-4} \text{ } ^\circ\text{F}^{-1}$

- C_o = Isothermal compressibility of sample fluid, $\sim 7 \times 10^{-6} \text{ psi}^{-1}$

- $\square \Delta T$ = Downhole sample temp – surface opening temp, $^\circ\text{F}$

- Assumptions:

- ❖ α , C_o , and Volume are constant, and fluid remain single phase

- ❖ For C_o range 5 – 20, Δp range 100 – 25 psi/ $^\circ\text{F}$

How Does It Effect Results?

	Opening Pressure psia	API	GOR SCF/STB	Live Oil Density gm/cc	Live Oil Viscosity cp	FVF RB/STB	Mol. Weight STO / LO
MRSC Gallon	<u>8000</u>	<u>37.2</u>	<u>1585</u>	0.6766	<u>0.45</u>	1.655	<u>218</u> / <u>72.2</u>
MPSR 450 cc	13,800	35.4	1532	0.688	0.78	1.696	223/73.8
SPMC 250 cc	15,000	35.0	1534	0.685	0.8	1.688	224/73

How Does It Effect Results?

	Psat	Aspal. wt%	Asphal. Onset- Press.	Sulfur wt%	Wax wt %	Pour Point	Co 10⁶
	psia		psia			DegF	Psi⁻¹
MRSC 1 Gal	<u>4498</u>	<u>0.19</u>	<u>7550</u>	1.04	5.91	<u>-39</u>	<u>4.96</u>
MPSR 450 cc	4300	0.67	8250	1.217	3.16	-5.8	7.57
SPMC 250 cc	4280	0.65	8550				8.17

Evidence of Asphaltene Precipitation



Pyrex Tube



**Nylon Filter
0.45 µm**



**Flat
Piston**

Asphaltenes can stick to walls and crevices, steam cleaning does not remove!

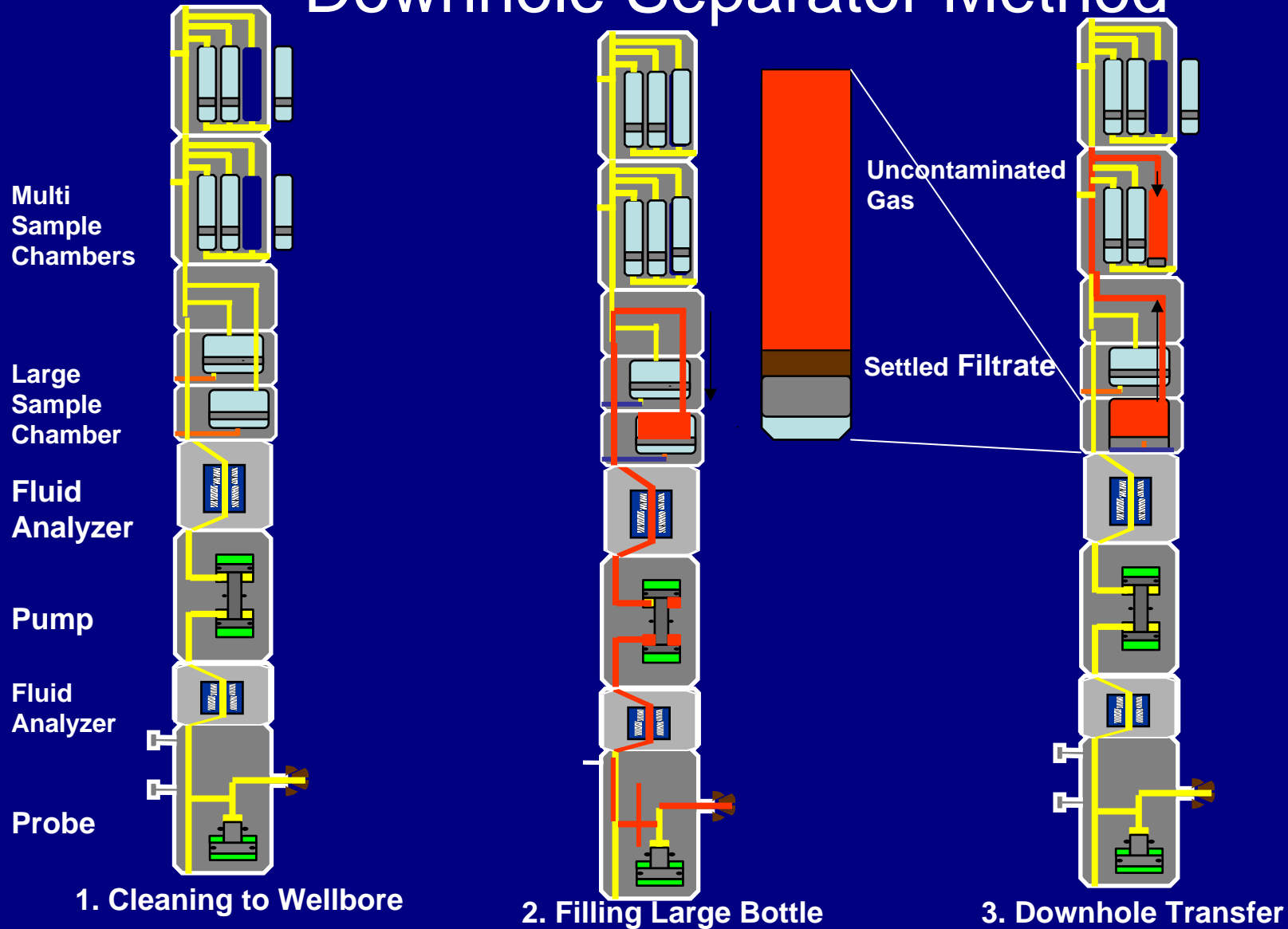
Bottle Rinsing

- Steam Cleaning does not remove sticking asphaltenes,
- Sampled gas or light oil can act as a solvent dissolving the residual asphaltene,
- Pre-sampling rinse with solvent ensures clean start,
- Post-sampling rinse answers inconsistencies and can flag missed solids precipitation.

Acquisition

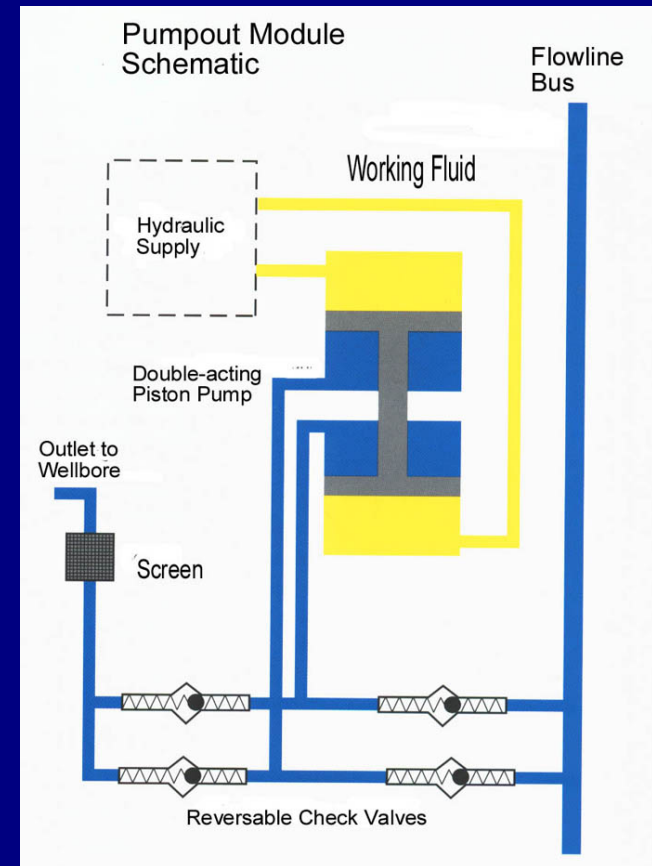
New Sampling Techniques to
Minimize Filtrate Contamination

Downhole Separator Method



Gravity Segregation Method

1. Capture an up stroke, to trap water behind the hydrocarbon
2. Close exit to wellbore
3. Stop for 1 minute to allow for gravity segregation,
4. Pump slowly into a small chamber.
5. Repeat as needed.



DST Cost Deepwater Well in the Norwegian Sea

Time Breakdown	Days
Clean Well, displace to brine	3
Packer + perf. on wire line	2.5
WOW prior to run Fracpac string	2
FracPac	6
WOW/problems with rig tensioner	4
Run DST string, incl. dummy space out in deep water	7
Flow well	3
Build-up	2
Kill well, pull string	2.5
Total Test Period	31.5



Total DST cost: 17 million USD
(almost same cost as drilling the well)

Big cost saving potential with use of
WFT of FTWD technology as DST
replacement

Comparing Results of Formation Testers to Actual Production

PVT Property	Wireline Sample	Flowline Results
GOR (SCF/STB)	1644	1638
API Gravity	40.5	39.2
Molecular wt	66.5	64.95
Density (gm/cc)	0.68	0.66
Viscosity (cp)	.405	.359
Saturation Press. "P _{sat} " (psi)	4552	4822
FVF "B _{oi} " (STB/RB)	1.9215	1.928
Compressibility (psi ⁻¹)	8.58 x10 ⁻⁶	8.08 x10 ⁻⁶
CO ₂ (mole%)	0.14	0.148

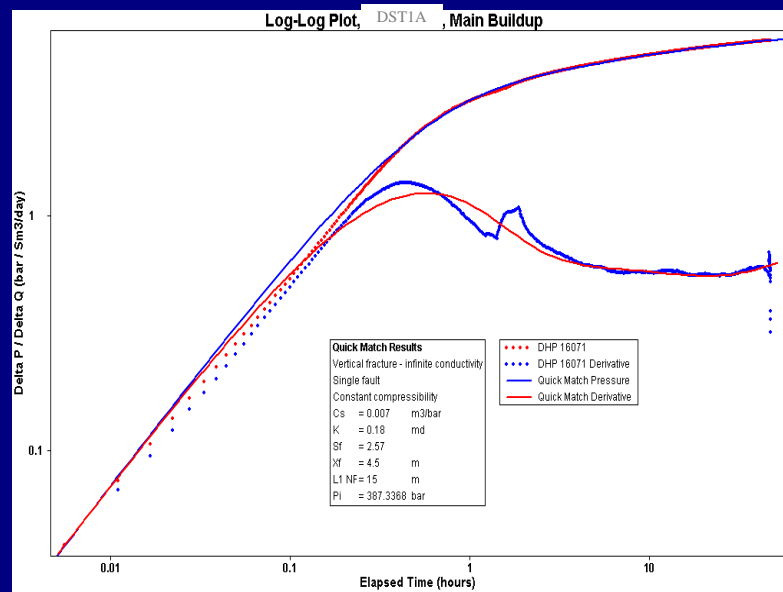
Mini-DST vs. Regular DST Deepwater Exploration Well

Full Scale DST

Test time : 31.5 days

DST cost : approx. 17 mill. USD

54 m perforated interval

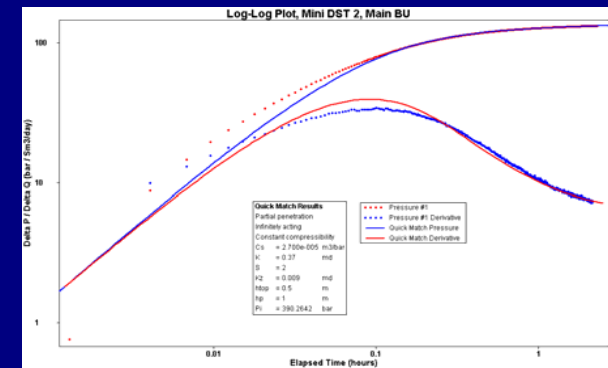


Three WFT mini DST's

Logging time: 2 days

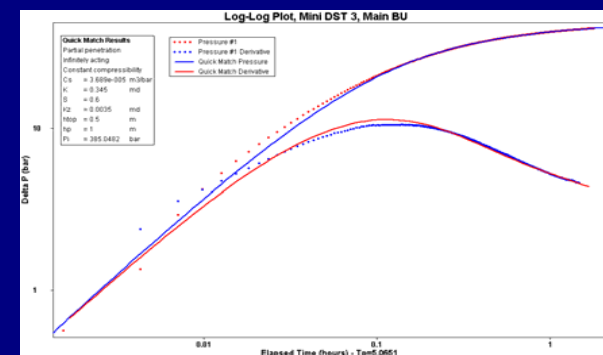
WFT mini DST cost 0.9 mill. USD

Mini DST#2 @ xx06 m

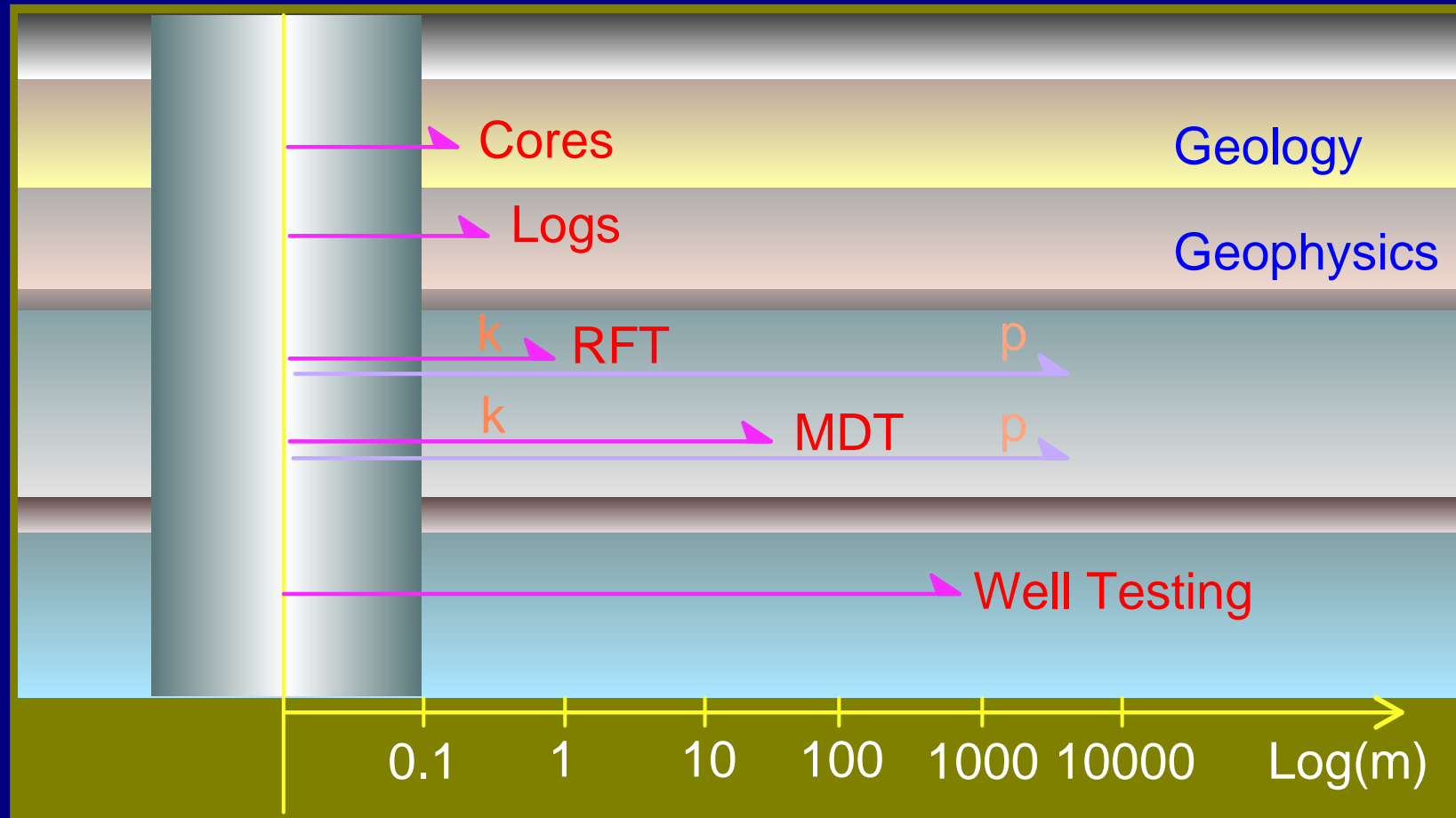


Similar results

Mini DST#3 @ xx63 m



Depth of Investigation Comparison

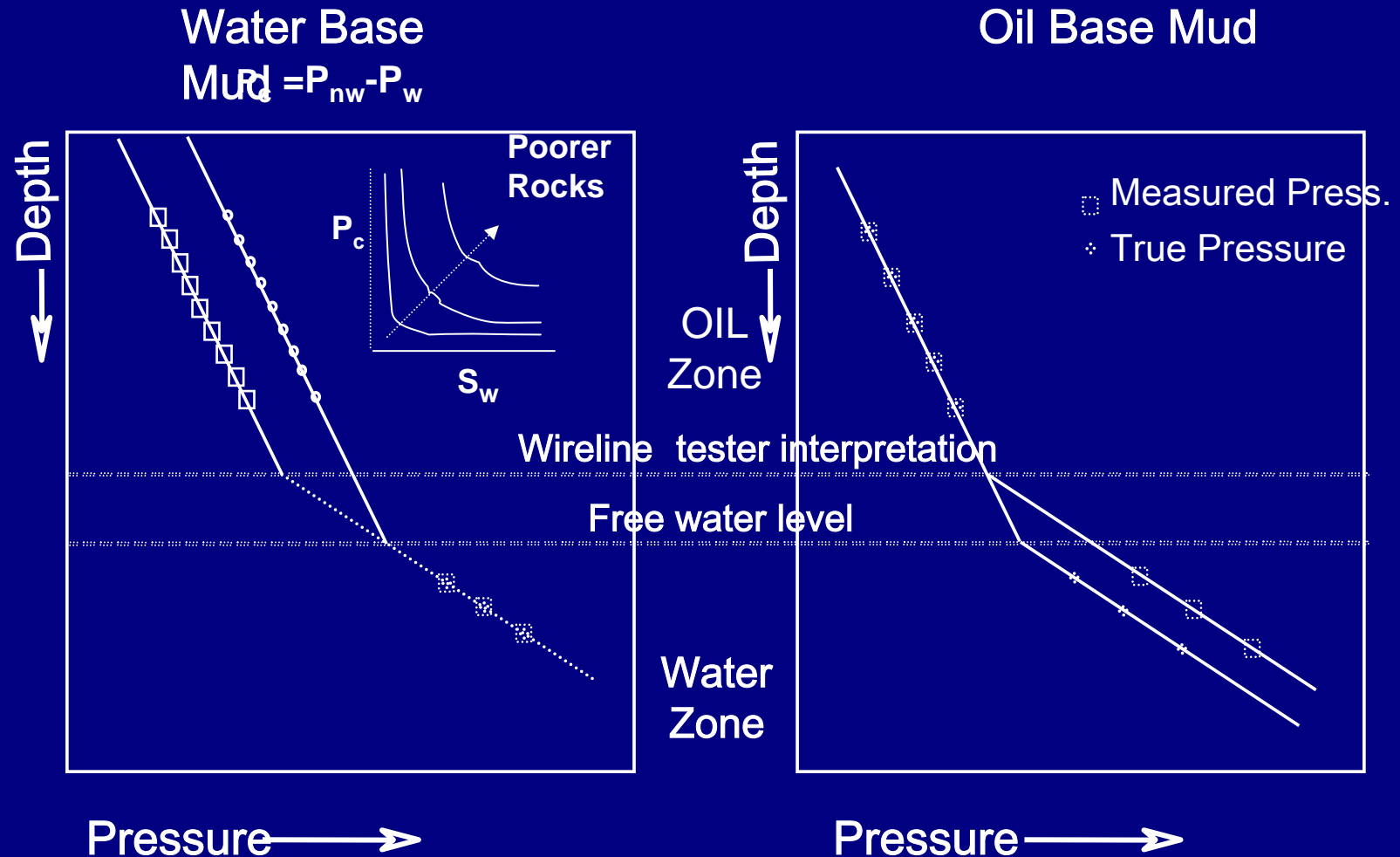


Interpretation Pitfalls

Errors of Pressure Measurement

- Depth, positioning & Instrument errors.
- Distance from gauge to actual measured depth,
 - fluid filling that column.
- Forced Linearity – Is it? (compositional grading).
- Heat introduced internally from tool electronics.
- Supercharging.
- Wettability effects.

Errors in Measured Fluid Levels for Water-Wet Rock Due to Wettability

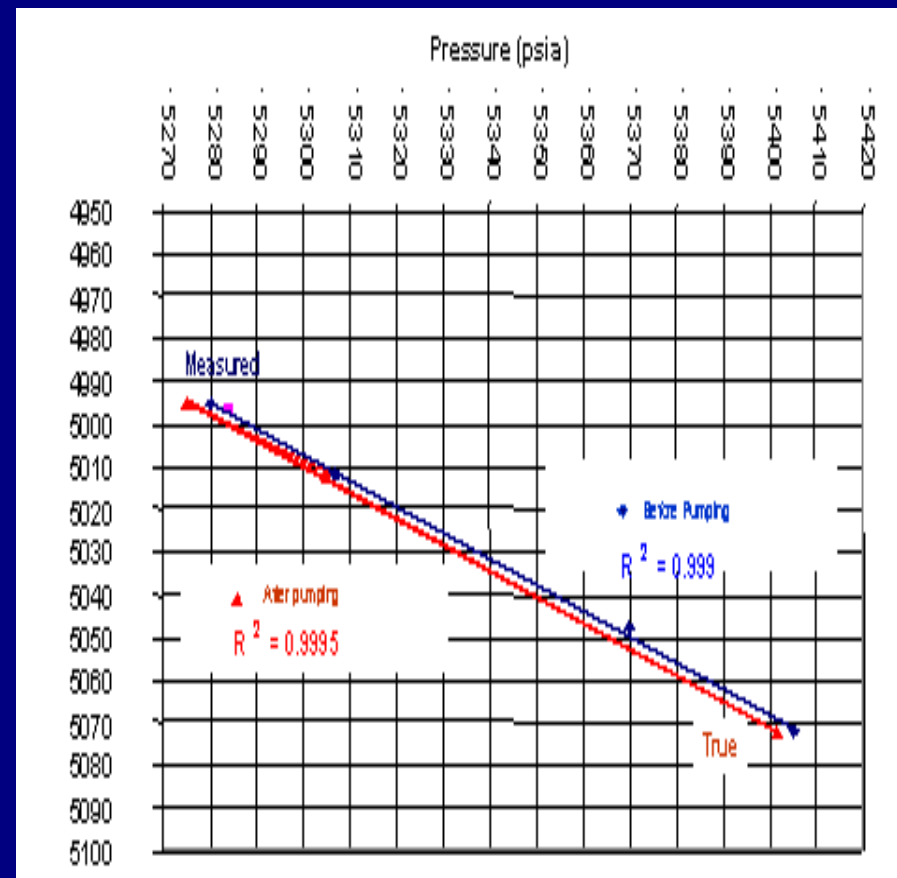
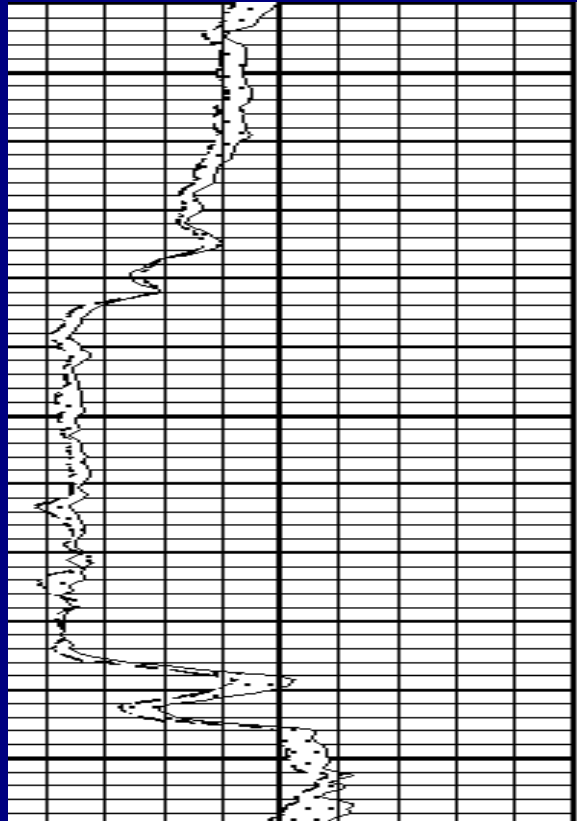


After Elshahawi et al. SPE 63075

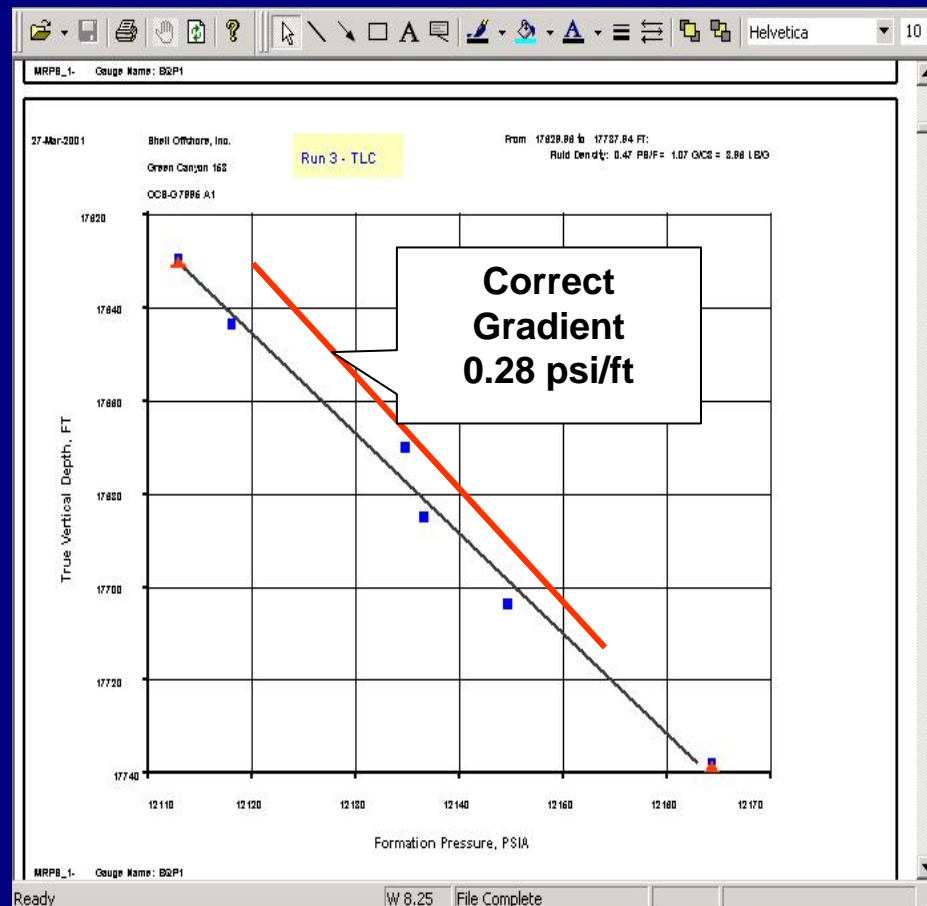
Wettability & Capillarity Effects, How To Detect and Correct Them

- For WBM/HC bearing or OBM/ water bearing,
 - check for supercharging first (comparing Pressure of multi Draw Down),
- Pump 2~5 strokes to get formation fluid to sand face,
- Take 20 cc pretests, stabilize to 0.01 psi for 30 s.
- This is the true formation pressure,
- Always take a pressure after sampling,
 - This corrects for supercharging and wettability effects.

Blocky Formations Have an Even Gradient Shift



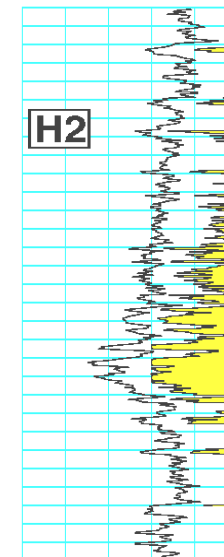
Fining Upward Sequences Have an Increased Gradient



GRC		
30	API	130

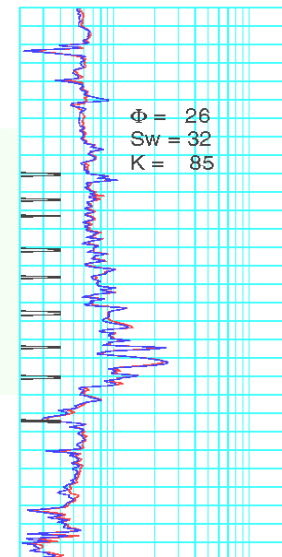
Depth
FT

SEMP		
.2	OHMM	20
SEDP		
.2	OHMM	20



N/G=47%

17800
**68 NFO
(63 TVNO)**



CONCLUSIONS

- The proper planning and execution of WFT surveys can lead to a very solid understanding of the reservoir fluids.
- WFT successfully obtained rock and fluid representative properties for most conditions.
- Non representative fluid samples can lead to the wrong economic evaluation of a prospect.
- Wettability effects on pressure interpretation can lead to wrong Fluid contacts and lost reserves.

Extra Material

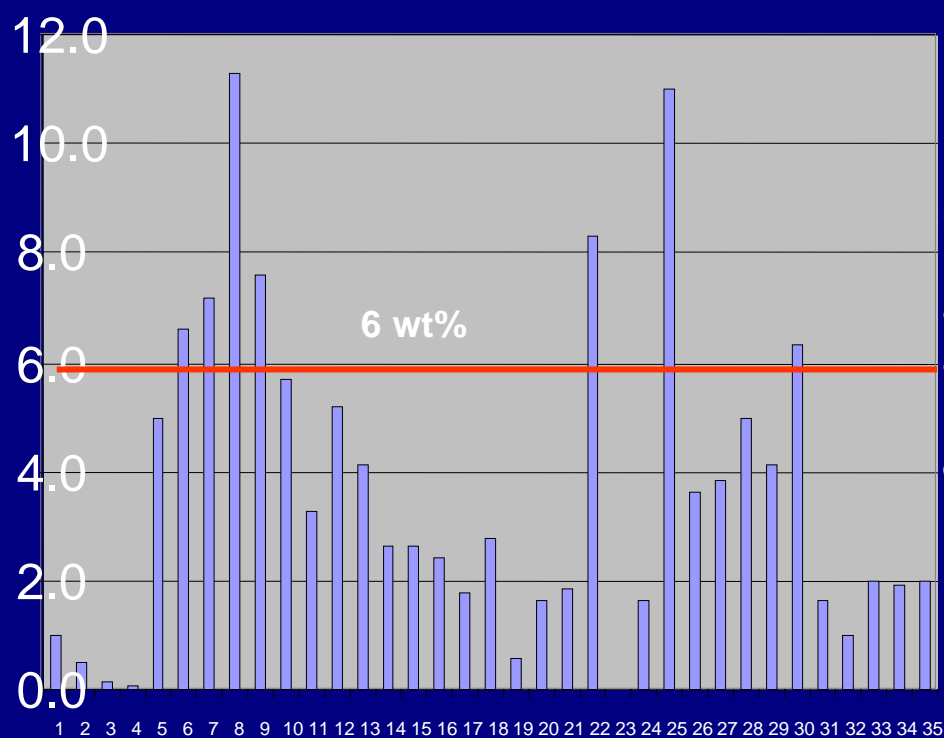
Prediction Score Card for Method Described in SPE 39093

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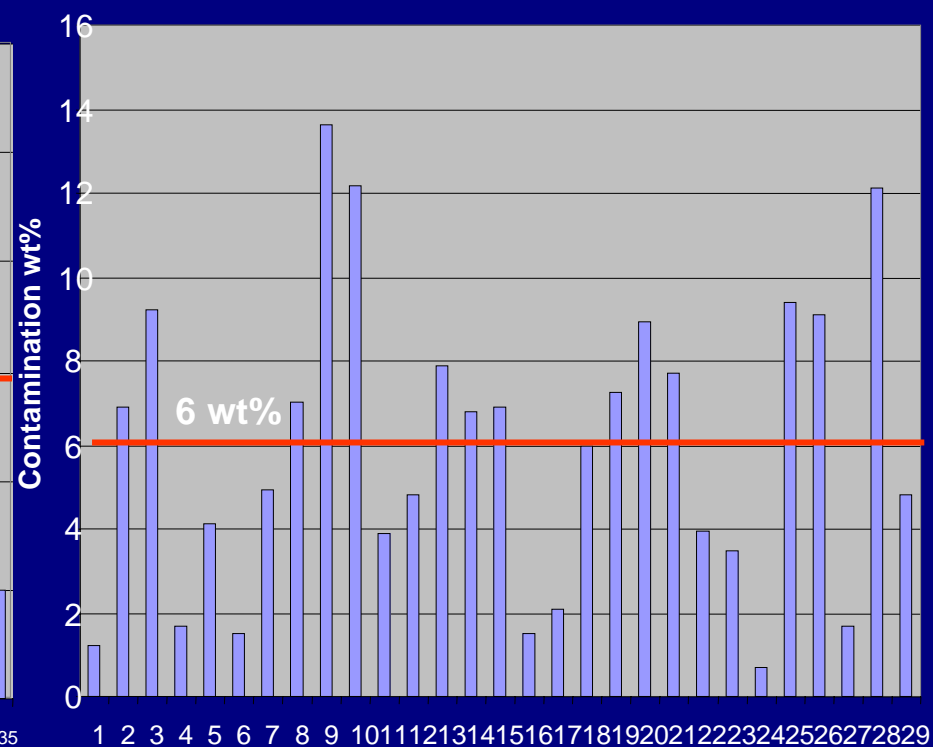
	API	GOR	Mole wt	Viscosity	FVF	Psat	Density
Actual	30.14	1038	93.26	0.873	1.39	4378	0.752
Predicted	26.9	1016	95.0	1.281	1.37	5311	0.75
Actual	37.7	5413	38.45	0.1213		10567	0.5107
Dens Pred	38.8	4987	38	0.111	3	7633	0.510
FA Pred	40.4	5847	37.86	0.09	3.48	8201	0.505

Contamination Score Card

Contamination wt%



Latest Contamination Levels



Fluids Characterization

Reducing Fluid Property Uncertainties

High GOR oil (37 API, viscosity 0.3 cP, GOR 2000, Bo 1.9, Psat 8000)

Contamination level	Bo	μ	Psat	GOR	Onset of Asphaltene Precipitation	Cloud point
0 - 5 %	< 3%	< 3%	< 3%	< 3%	< 5%	
5 - 10%	< 5%	< 10%	< 5%	< 5%	< 10%	
10 - 15%	< 10%		< 10%	< 10%		
15 - 20%						
20 - 25%						
> 25%						

Uncertainties in corrected fluid properties as a function of contamination level for a certain fluid type

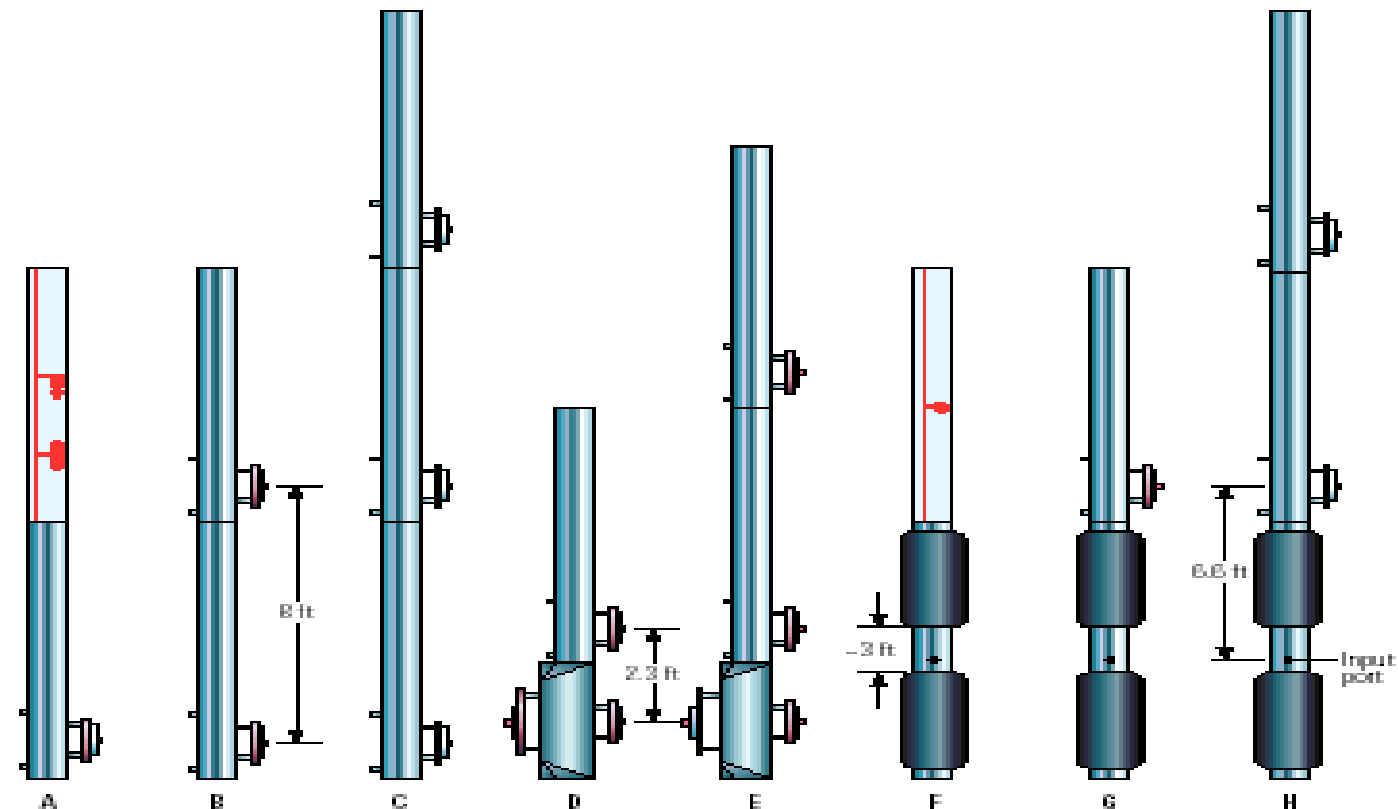
Wettability & Supercharging Solutions

- 1. Draw 10cc stabilize the pressure to 0.1 psi for 30 sec., then repeat the 10cc draw and stabilize pressure to 0.01 psi for 30 sec.**
- 2. Pump couple of strokes and repeat the steps. Pressure after pumping relief the supercharging and allow the measurement of the continuous phase pressure.**

Dangers of Missing Asphaltenes

- Underestimating the presence of asphaltenes can lead to wrong:
 - Subsea and wellhead design, chemical injection lines and insulation
 - Facilities design, no separate production trains, can upset all production if wrongly mixed
 - Pipeline design, incorrect pigging frequency can plug pipeline,...
 - Reservoir depletion strategy, wrong commingling strategy, skin wrongly treated

Different Interference Test Options



Usually	k_0	$k_0 k_u$	$k_u k_u$	$k_0 k_u fC_0$	$k_0 k_u fC_1$	k_0 and/or k_u	$k_u k_u$	$k_0 k_u$
Sometimes	k_0		fC_0					fC_1