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And special thanks to The American Institute of Mining, Metallurgical,
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Formation Testing:
Where Are We After 15 Years with Advanced Wireline Tools?

Pressures

Sampling and Downhole Fluid Analysis

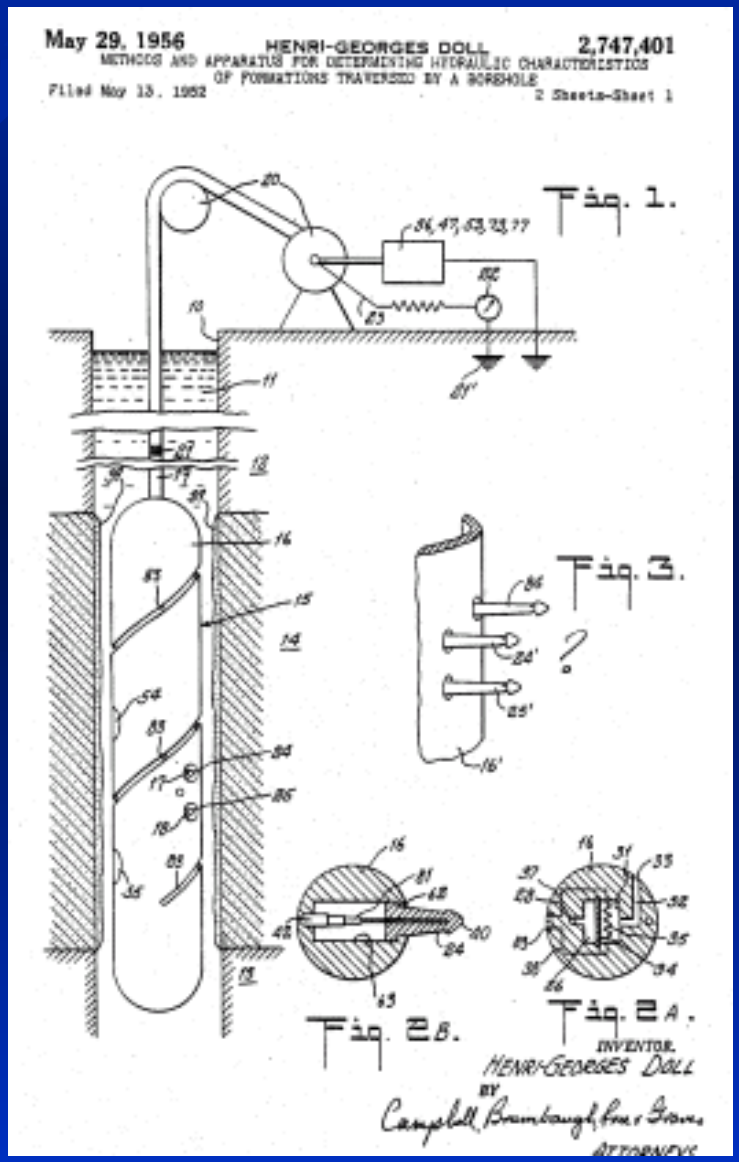
Transient Testing (IPTT)

In-Situ Stress Testing

Cosan Ayan

Schlumberger Reservoir Engineering Advisor

Formation testing-evolution


May 29, 1956 HENRI-GEORGES DOLL 2,747,401

METHODS AND APPARATUS FOR DETERMINING HYDRAULIC CHARACTERISTICS OF FORMATIONS TRAVERSED BY A BOREHOLE

Filed May 13, 1952 2 Sheets-Sheet 1

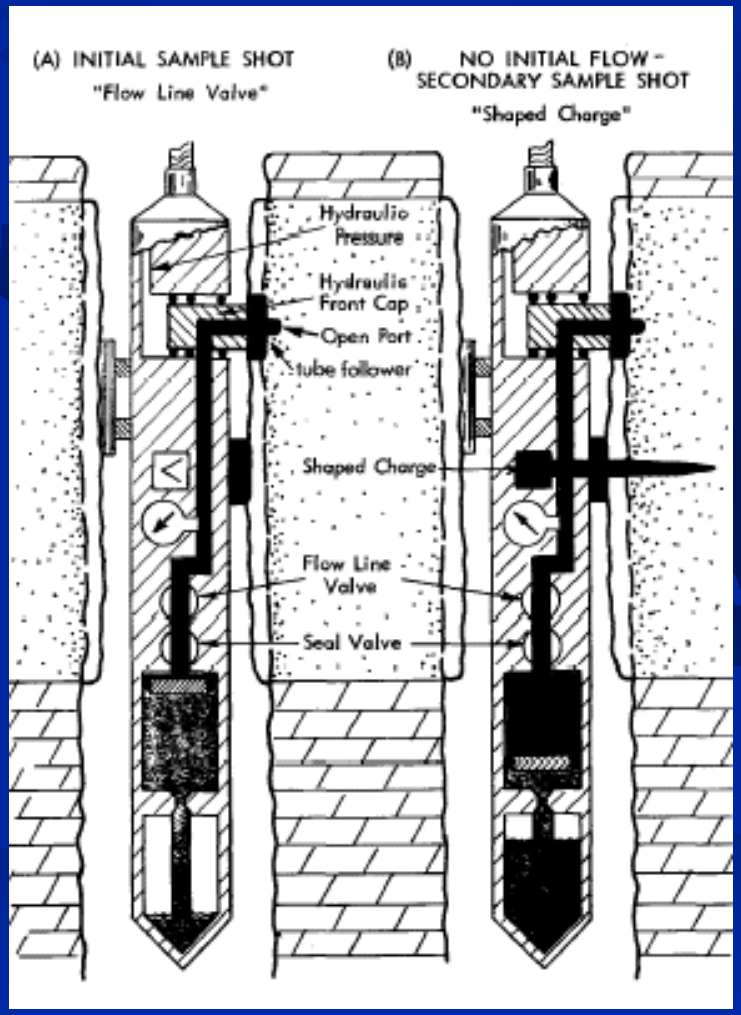
Fig. 1.

Fig. 3.

Fig. 2B.

Fig. 2A.

INVENTOR.
HENRI-GEORGES DOLL
BY
Campbell, Brumbaugh, Free & Graves
ATTORNEYS



Early formation testers: circa 1956

Latest formation testers~1991 onwards

Several service companies have a variety of tools

- Various probe assemblies, combination of probes
- Dual inflatable packers
- Downhole pumpout capability
- Several sample chambers
- Fluid identification modules
- Capability to work in cased hole

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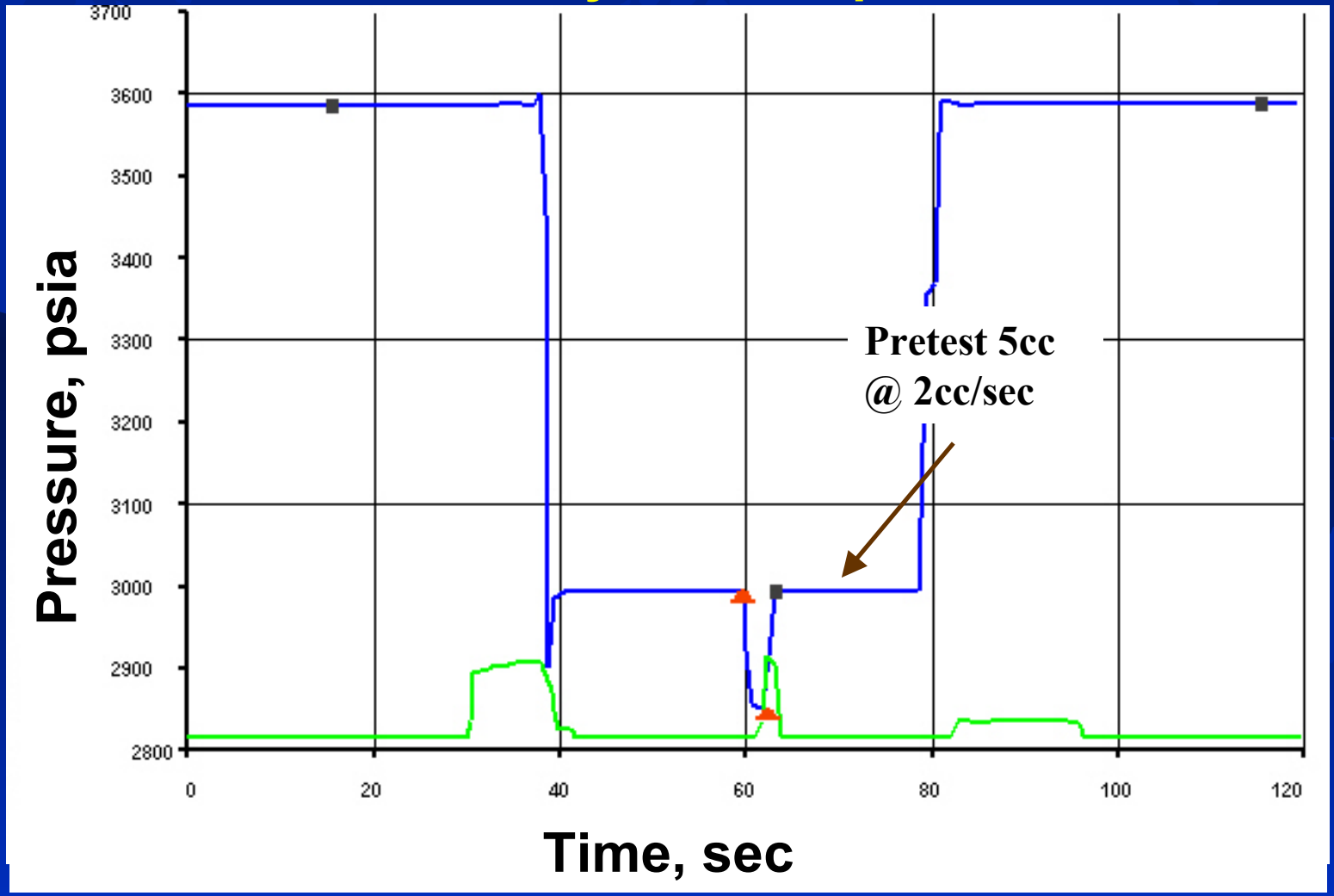
- In-Situ Stress Testing

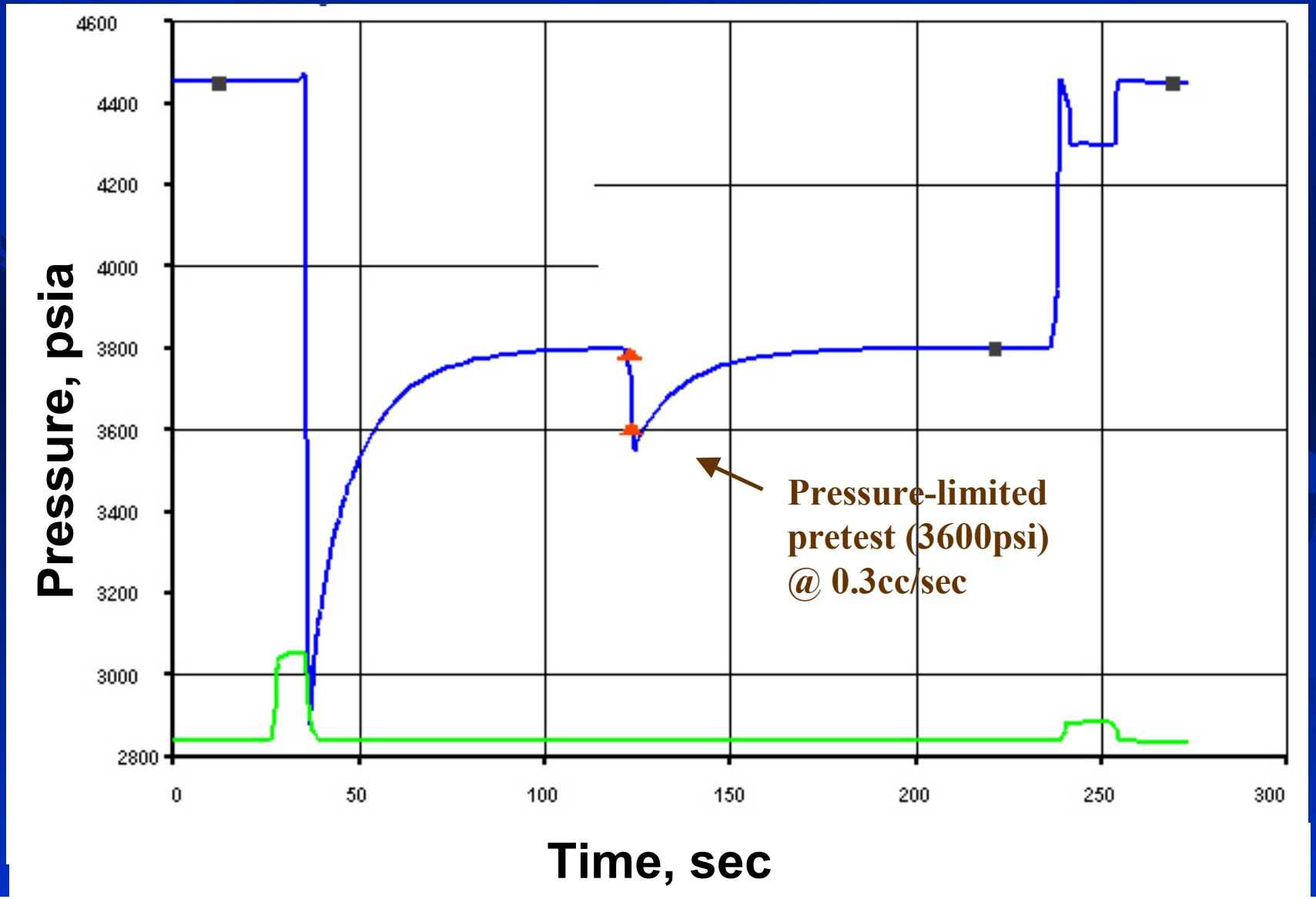
Pressure test: example-1

Mobility=75 md/cp

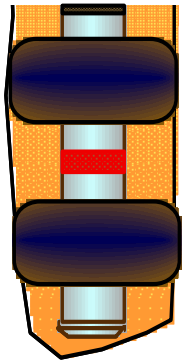


Pressure test: example-2

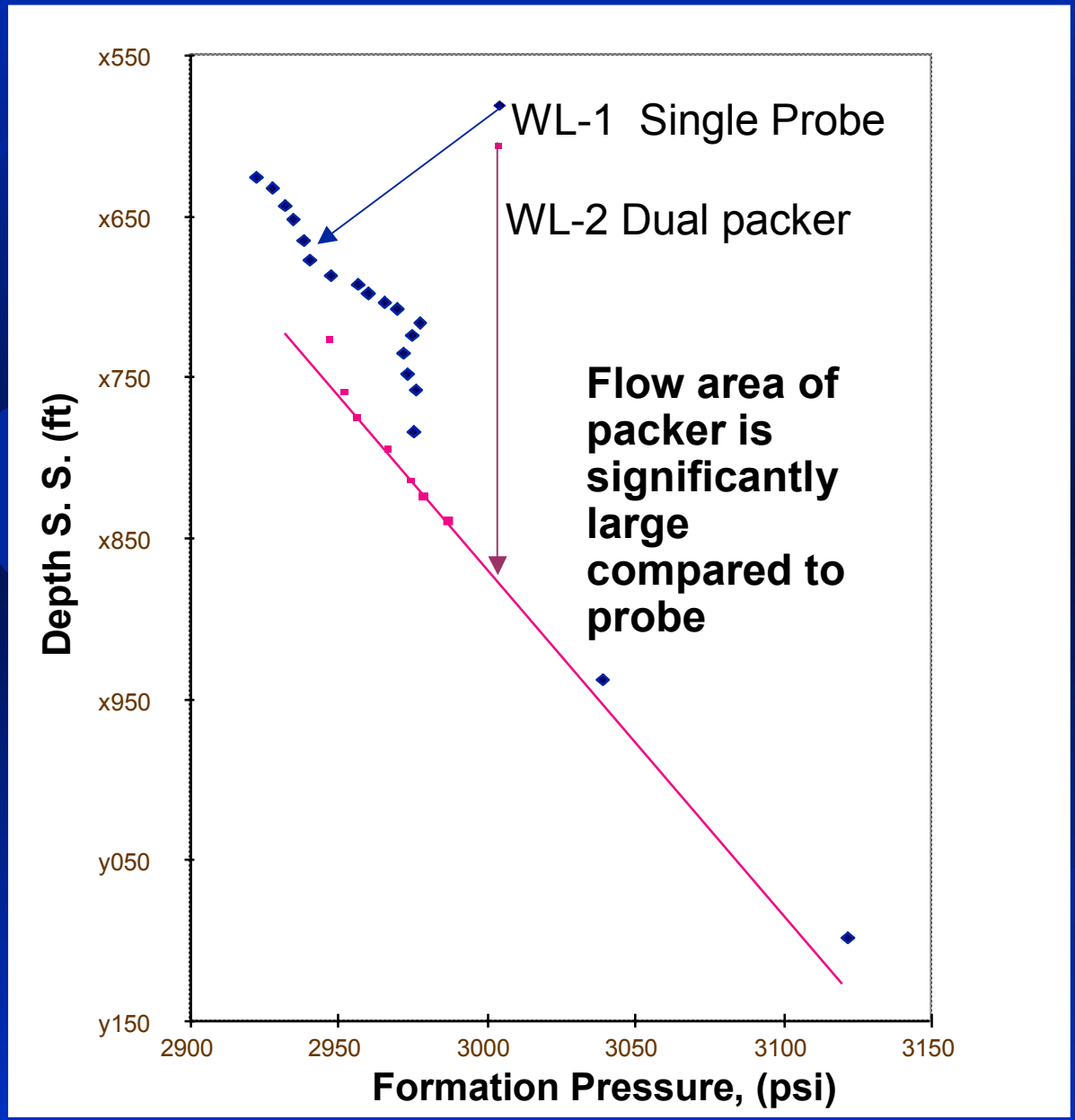
Mobility=0.2 md/cp



Pressure testing in very tight zones

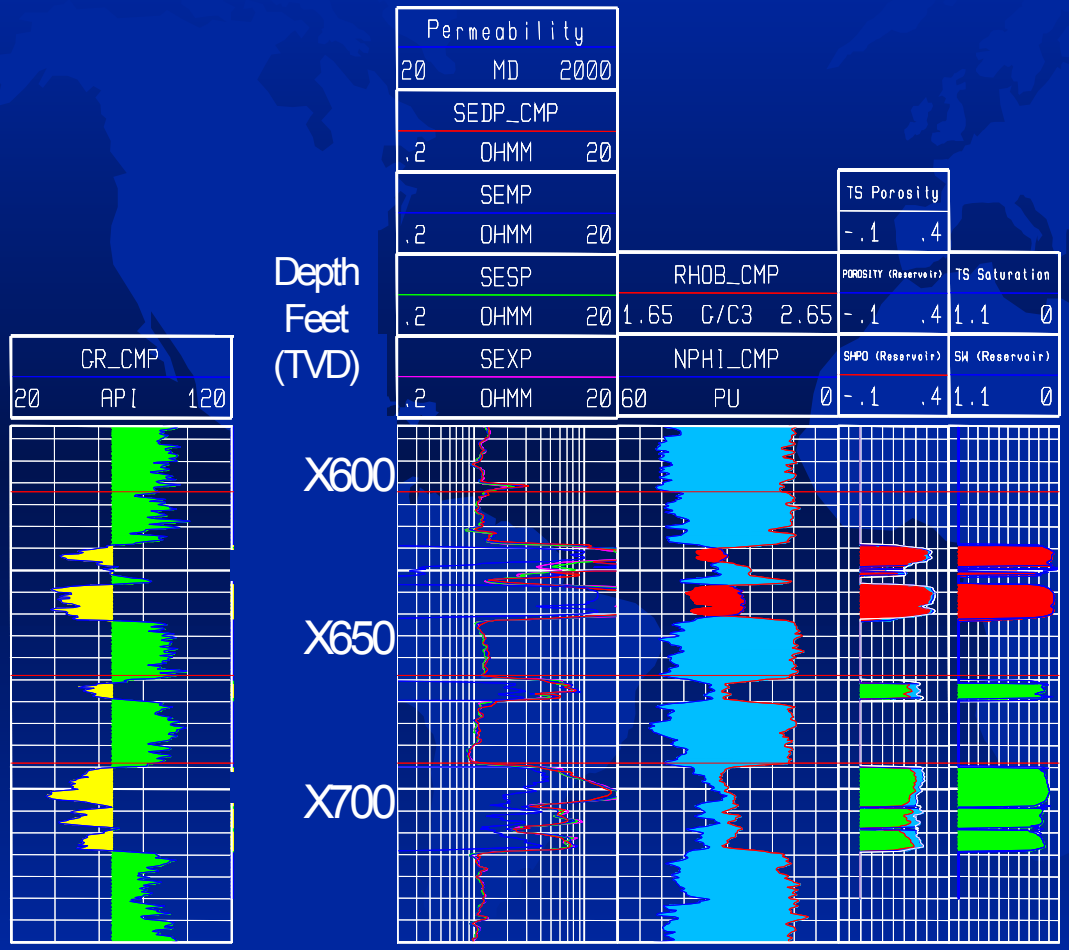


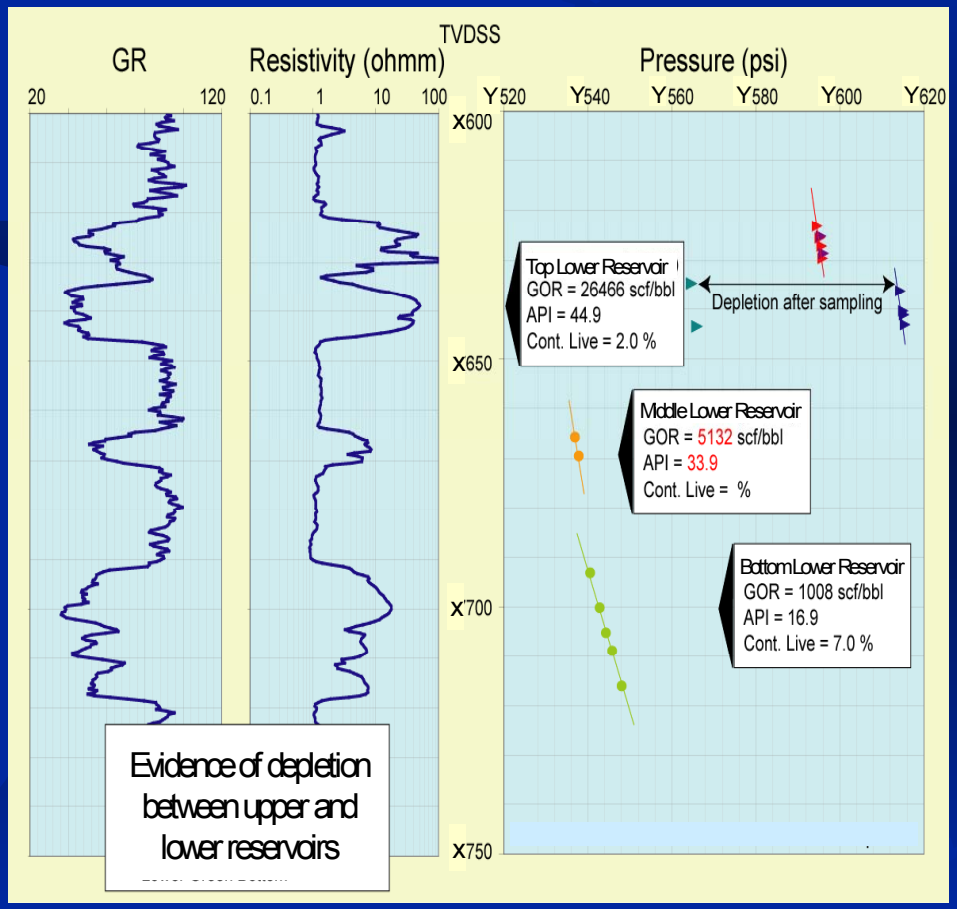
Dual packer type devices have increased flow area compared to a probe.



Pressures and depletion

SPE 94708-To be presented October-2005 SPE ATCE Dallas





Formation Testing:
Where Are We After 15 Years with Advanced Wireline Tools?

Pressures

Sampling and Downhole Fluid Analysis

Transient Testing (IPTT)

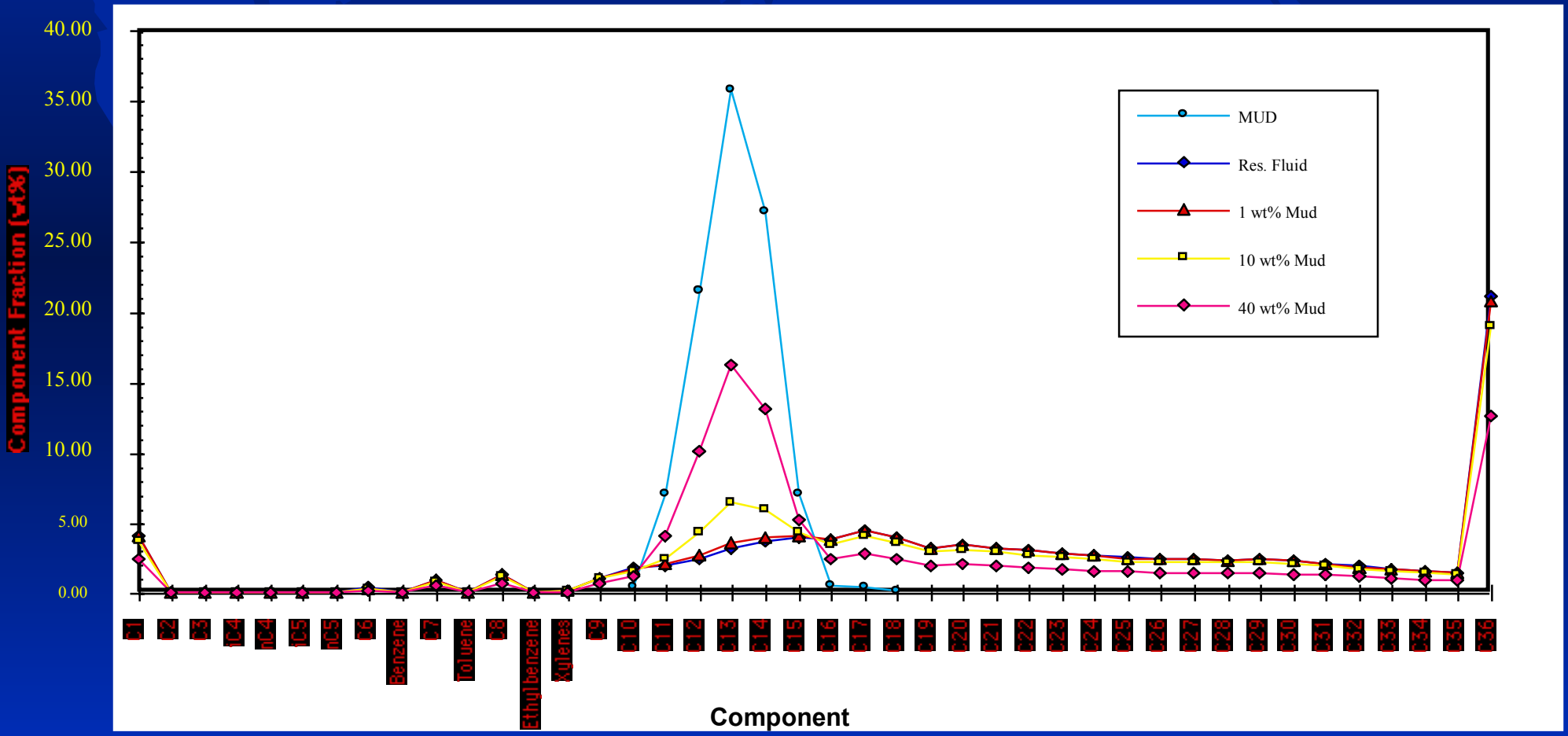
In-Situ Stress Testing

Sampling and downhole fluid analysis

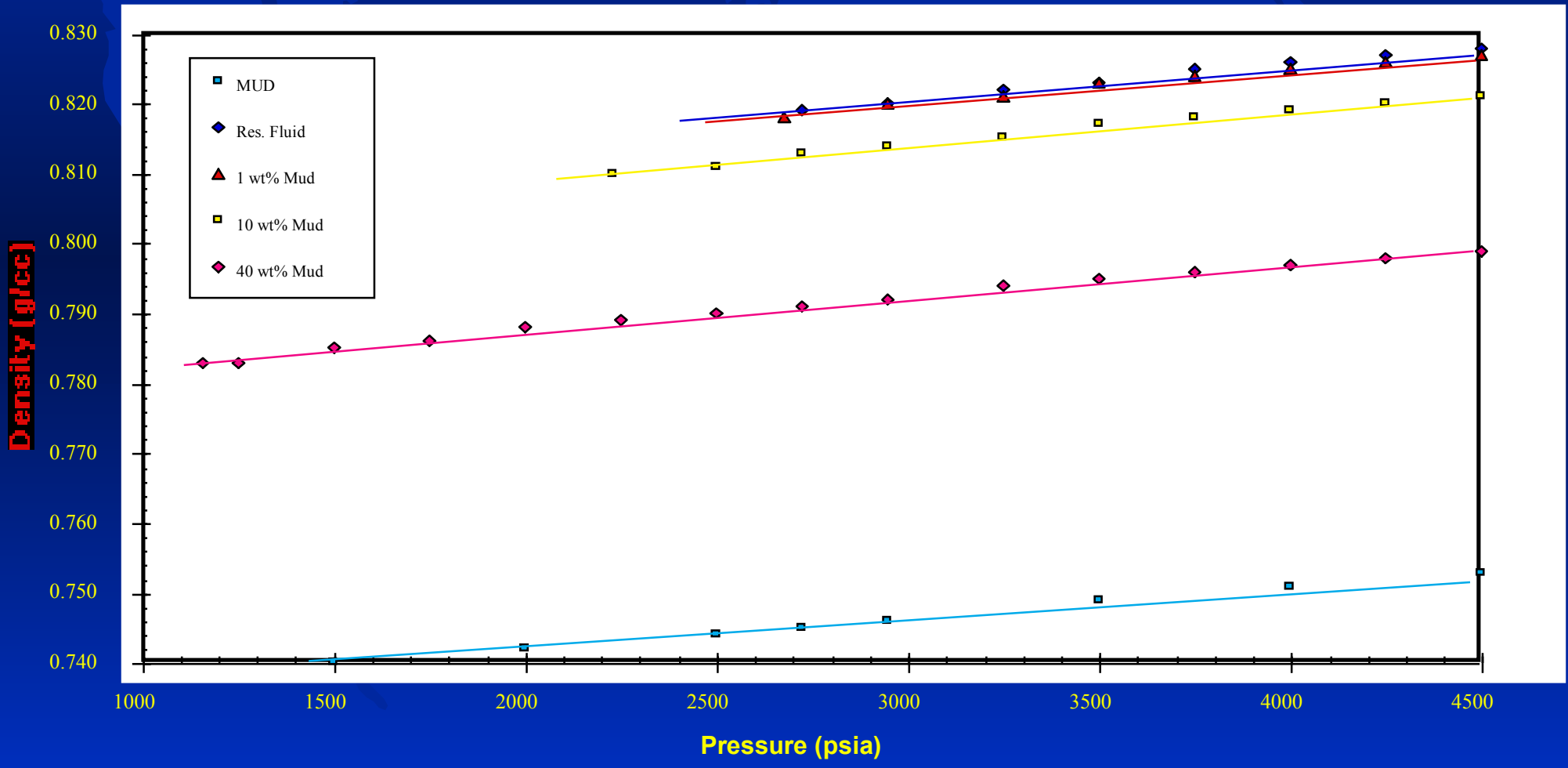
Good samples and fluid analysis depend on:

- **Reduced mud filtrate contamination**
- **Reduced drawdown during sampling to stay above phase separation envelopes**
- **Keeping samples above the phase separation envelopes at surface conditions**

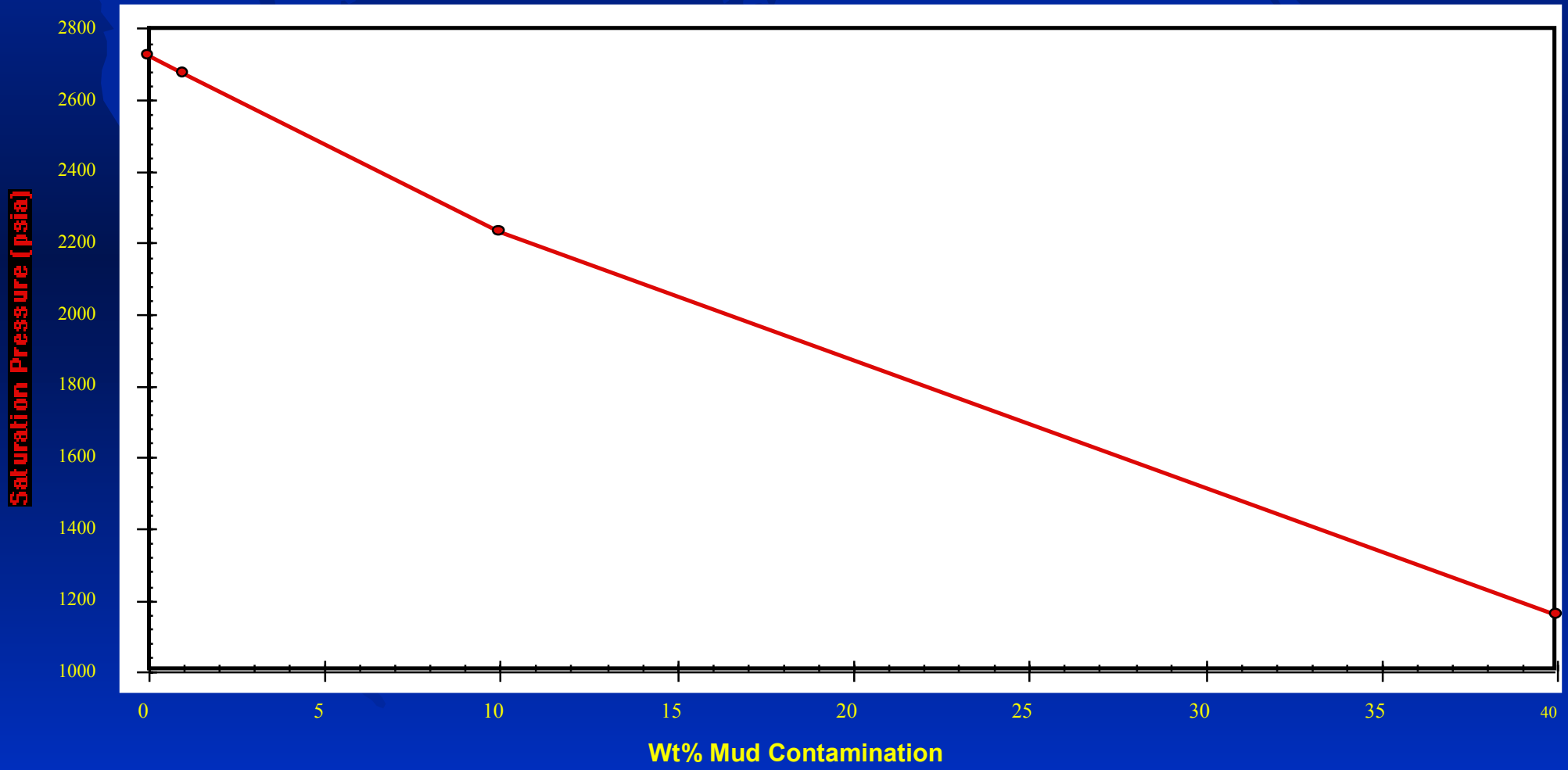
Black oil OBM filtrate contamination: composition



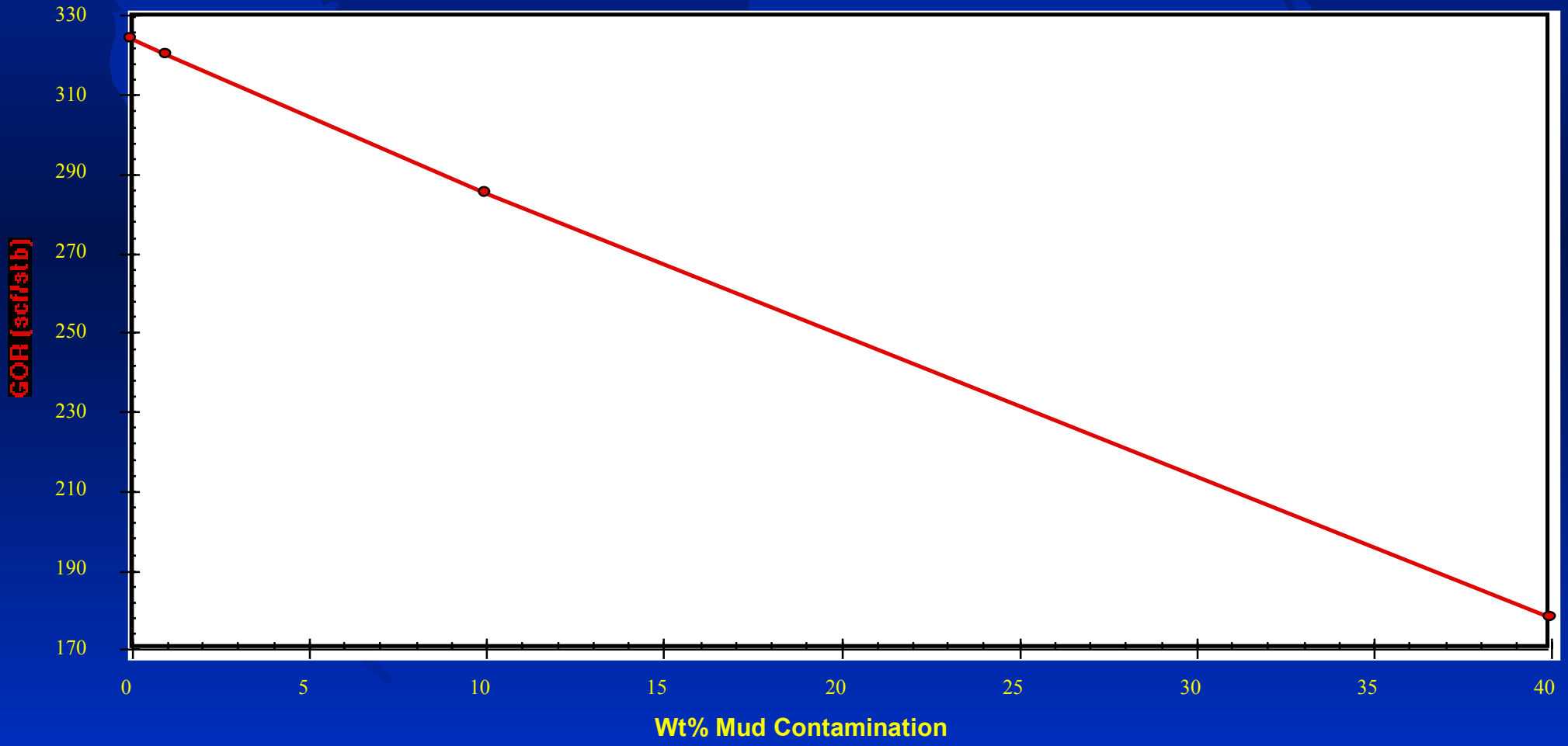
Black oil OBM filtrate contamination: density



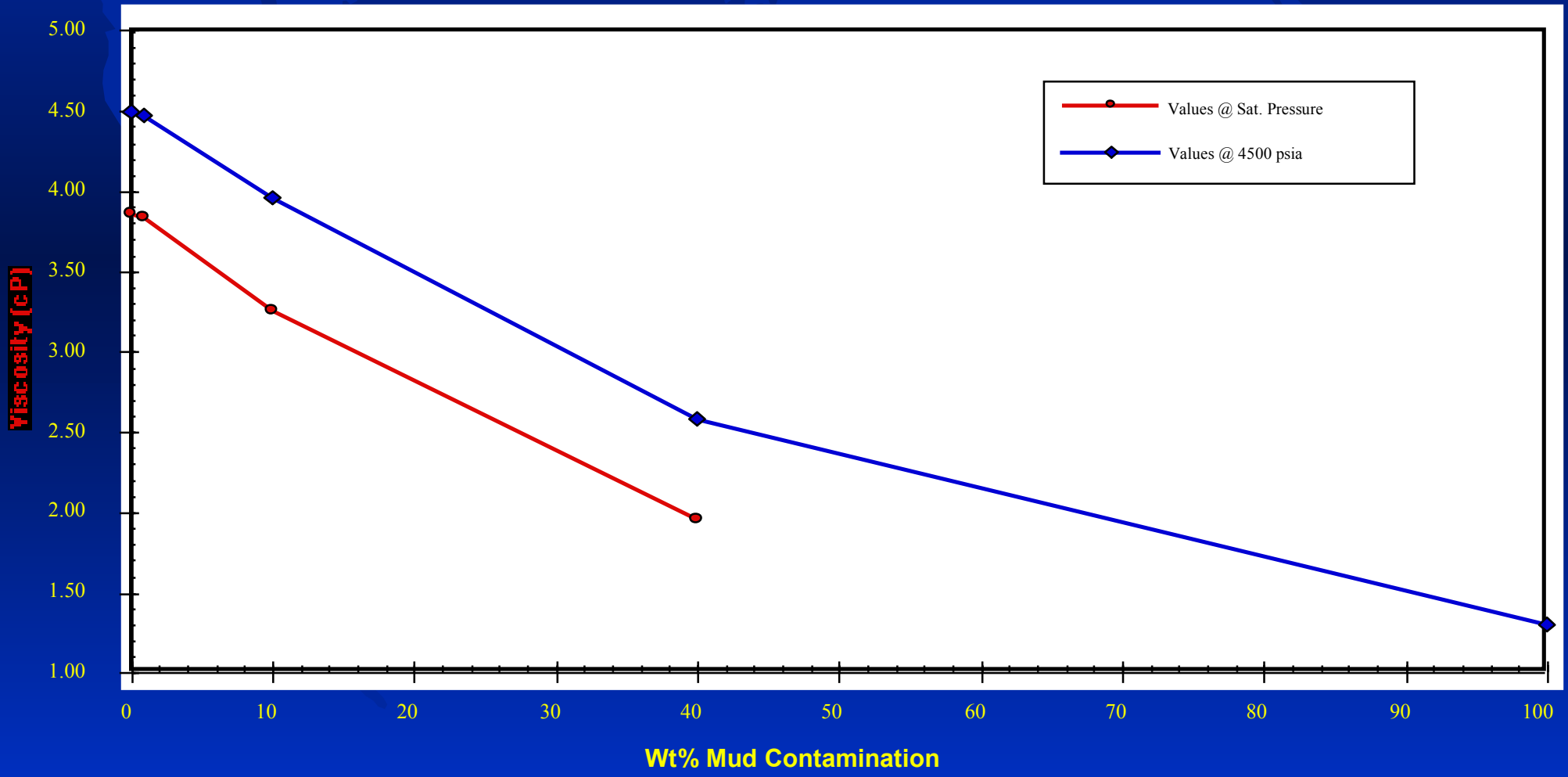
Black oil OBM filtrate contamination: sat. pressure



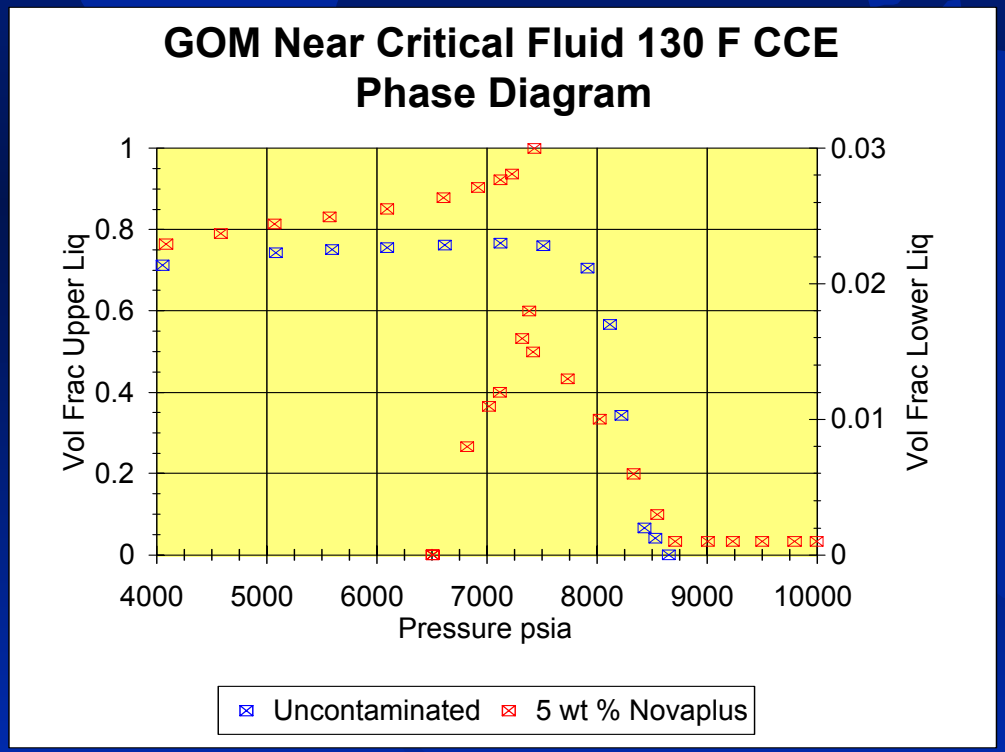
Black oil OBM filtrate contamination: Gas-Oil Ratio

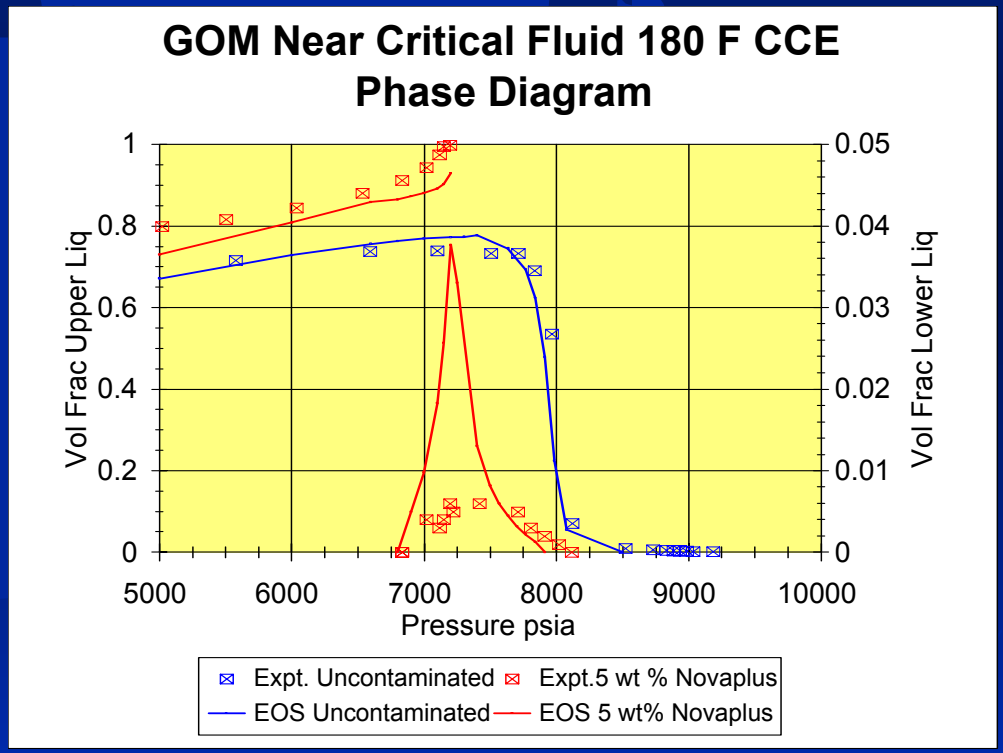


Black oil OBM filtrate contamination: viscosity

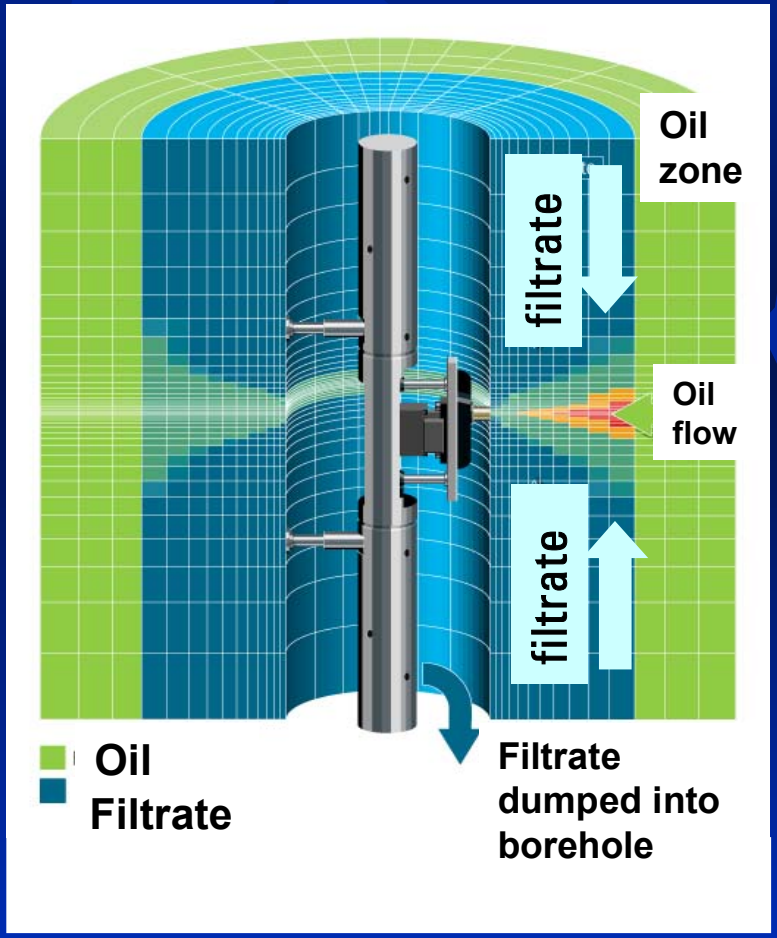


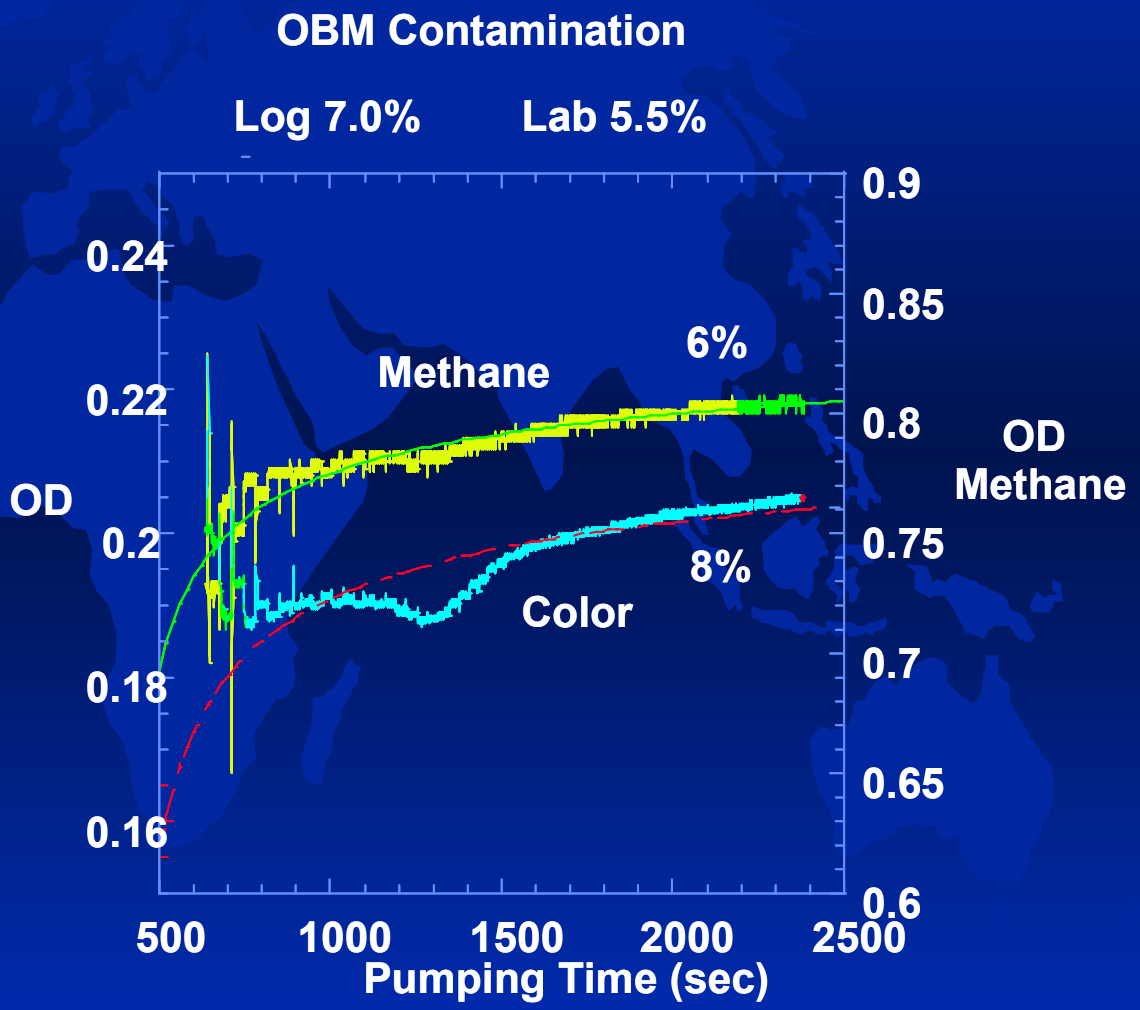
Effect of OBM on a near critical fluid



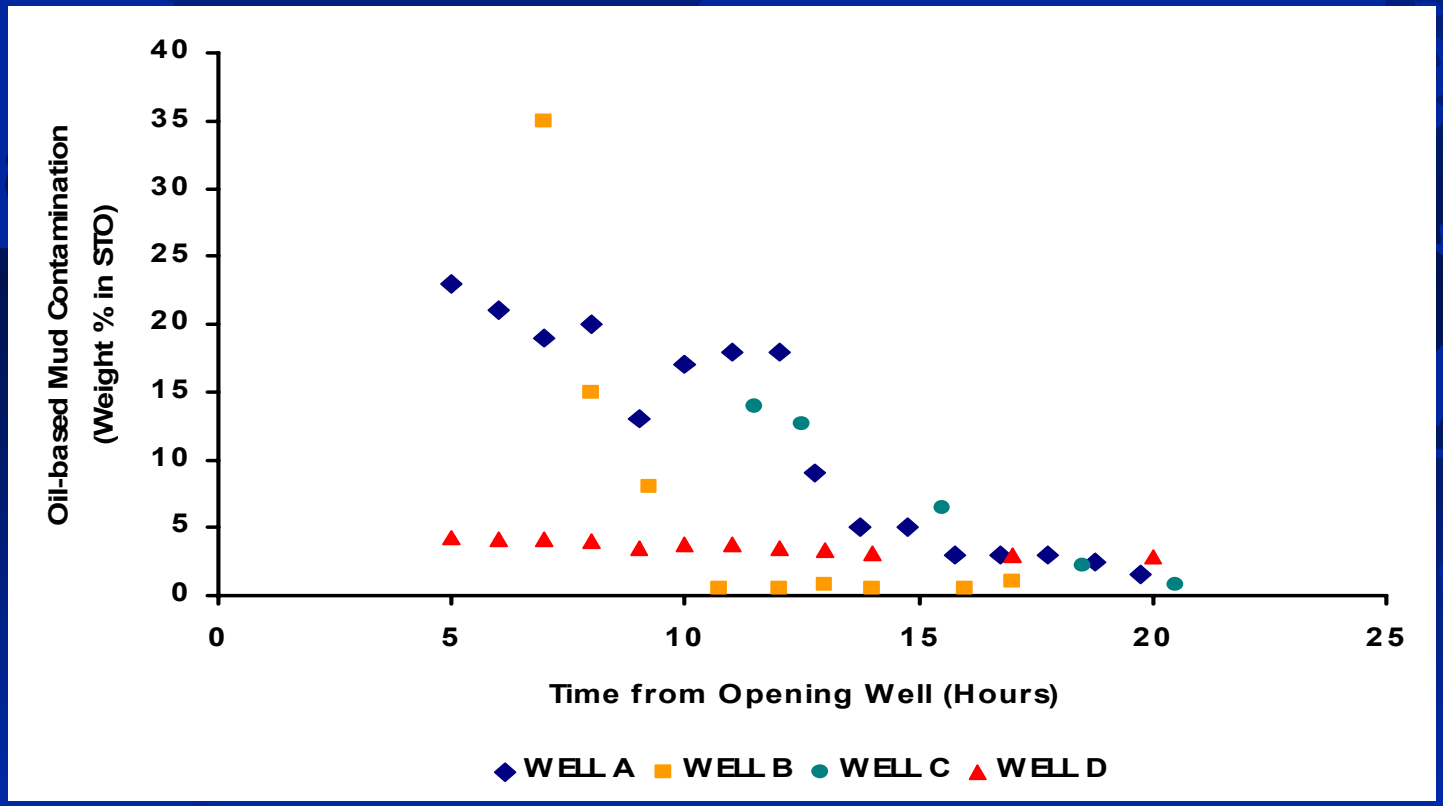


Filtrate cleanup for probe type testers

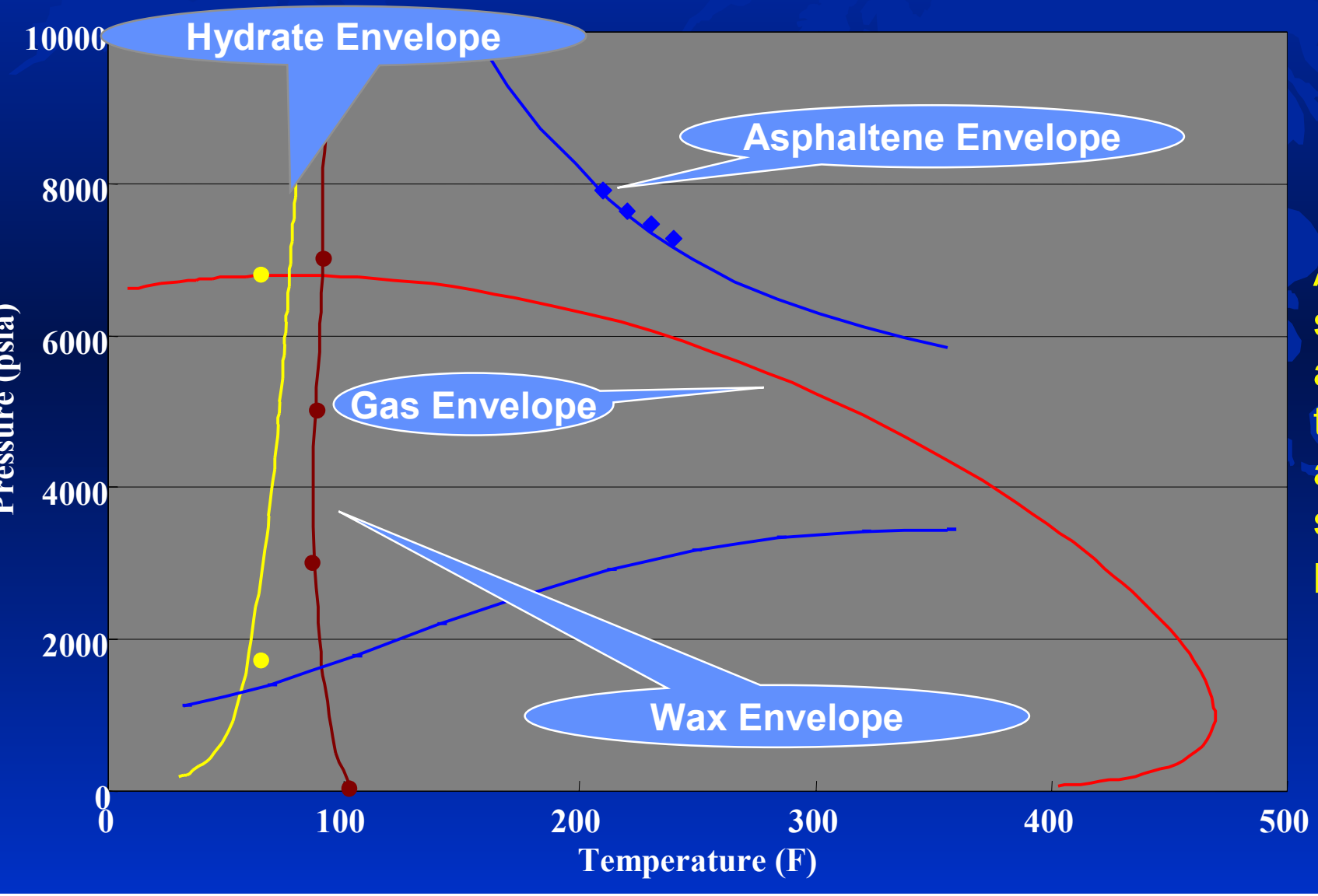




OBM contamination results during well test cleanup



Phase separation envelopes



Advanced samplers are now available to keep the samples above phase separation pressure(s)

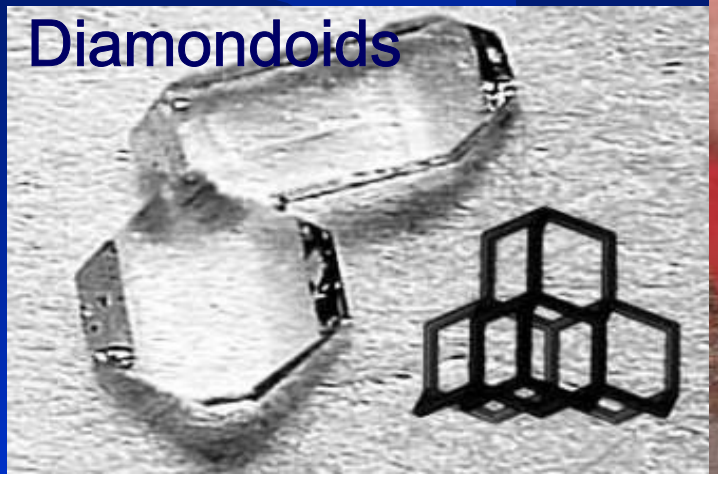
Oil chemistry and flow assurance

Tar Sand Extraction

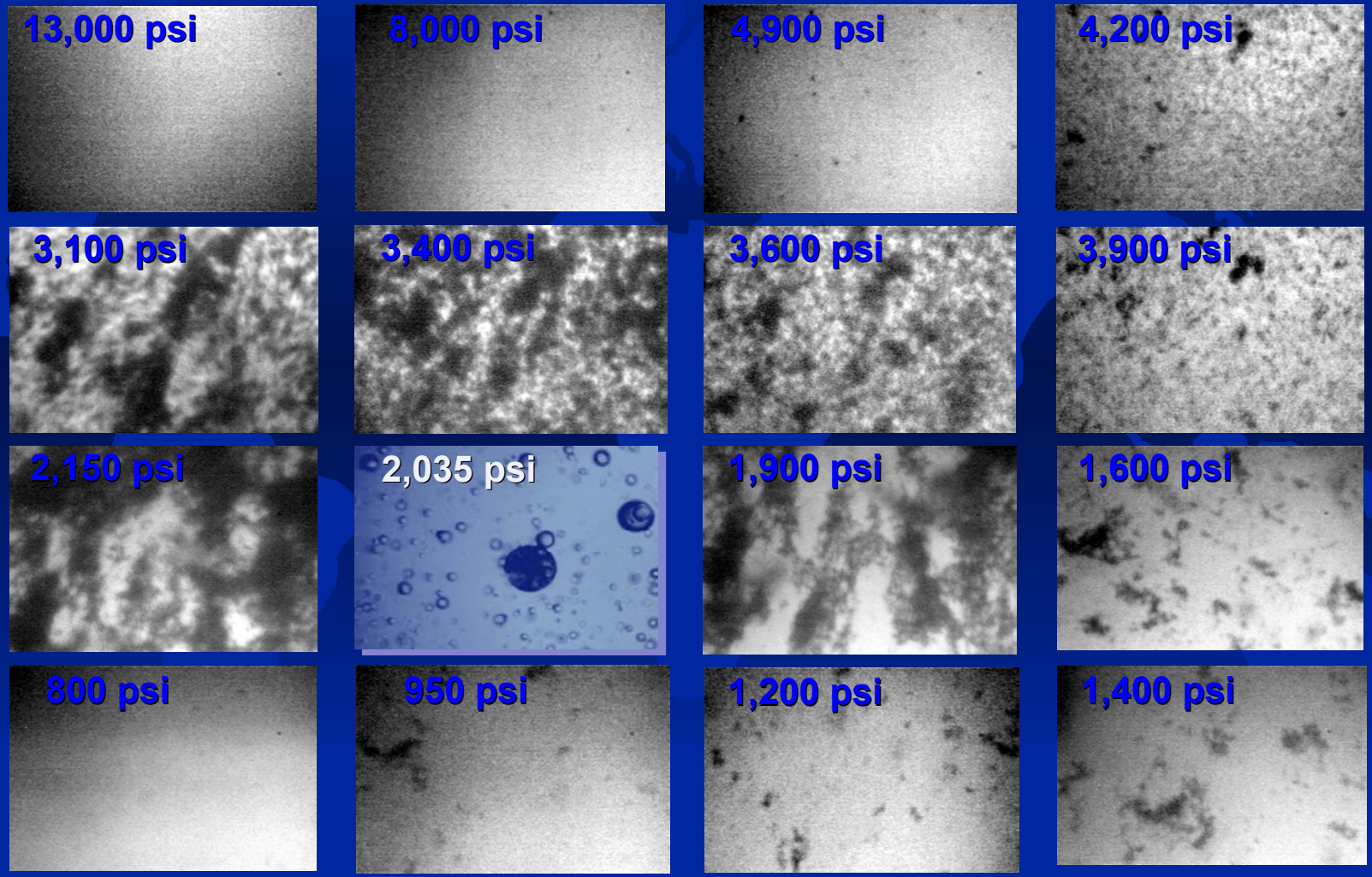
Emulsion Stability

Foaming Heavy Oil

Oil Chemistry has Huge Impact in ‘Typical’ Production.



Depressurization of OIL 2 @ Tres Oilphase-DBR HPM video freeze frames



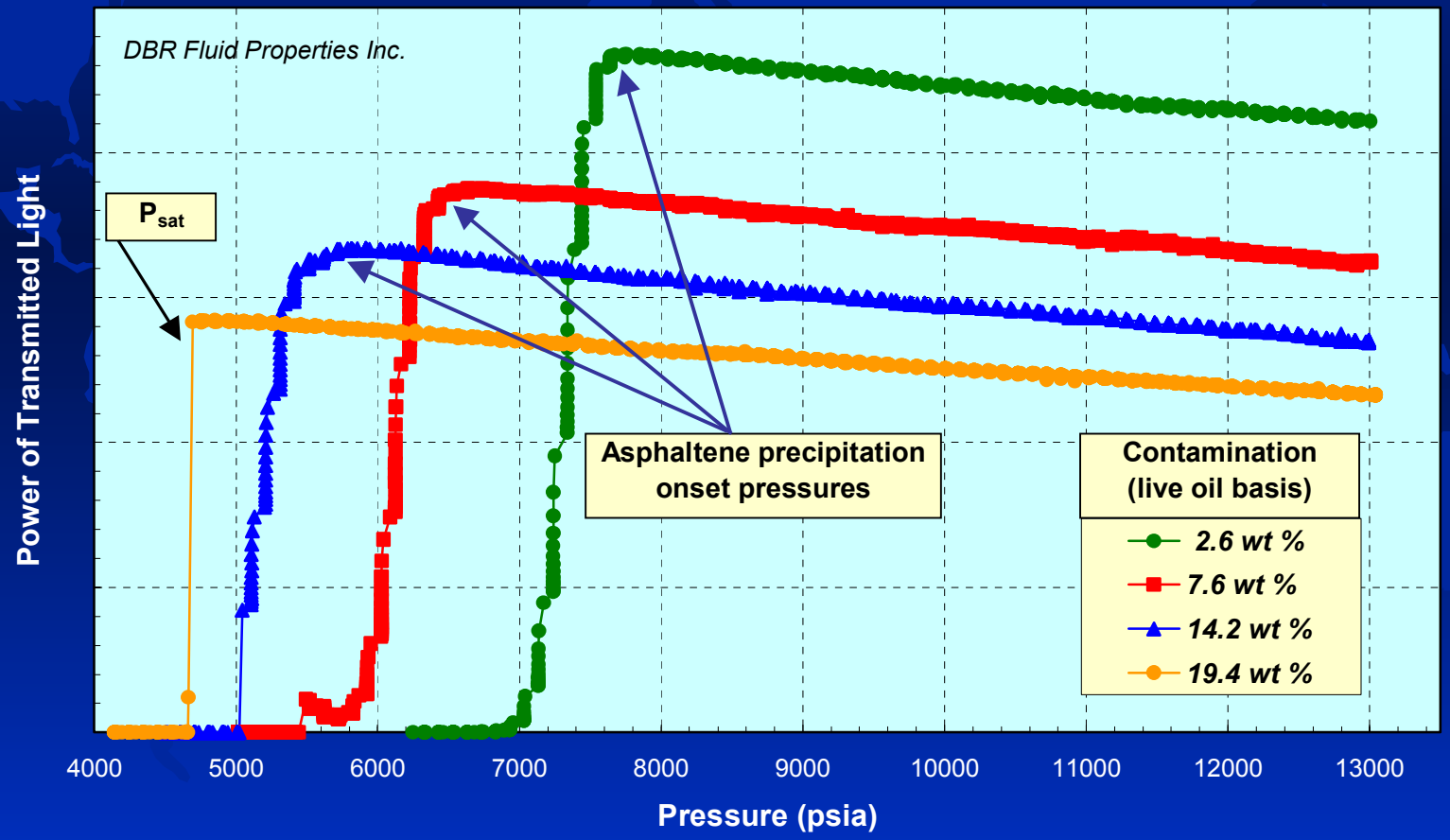
Evidence of asphaltene deposition

Pyrex Tube

Nylon Filter
0.45 μm

Flat
Piston

Effect of contamination
(Oil 1 and OBM)

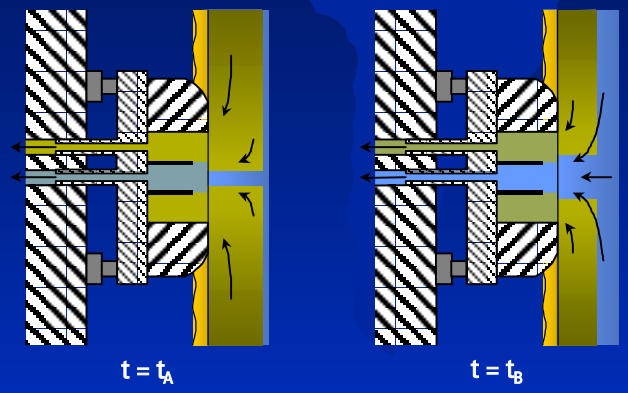


Emerging Sampling-Technique

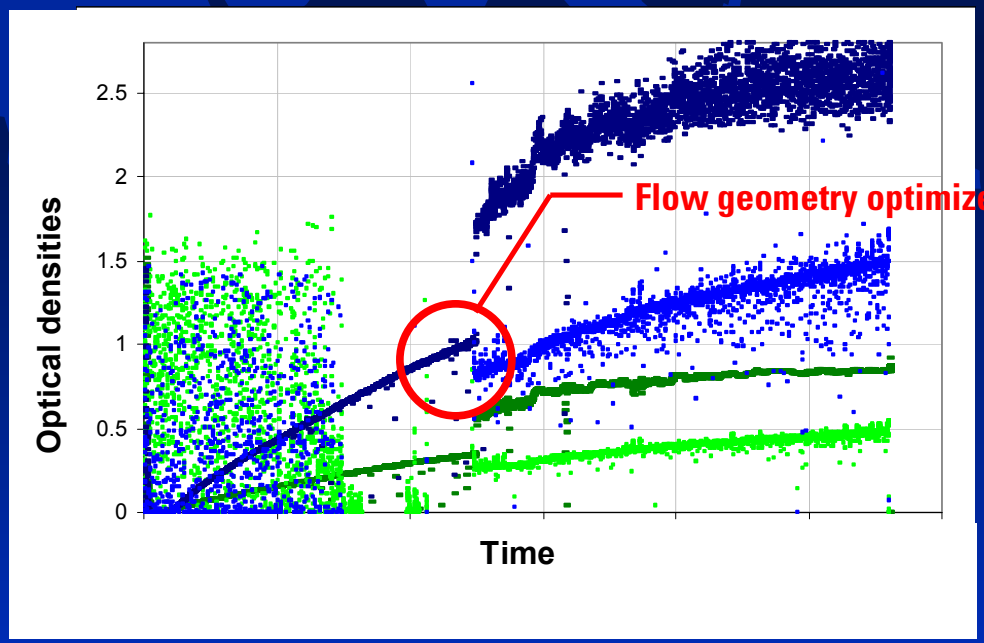
Flow thorough a special geometry reduces filtrate contamination much more rapidly than current methods

It is possible to achieve zero contamination

Oil Viscosity = much higher than filtrate viscosity
Sample with optimized flow geometry ~ 1 % contamination
(Min contamination with conventional sampling = 5 % in same formation after 18 hrs)

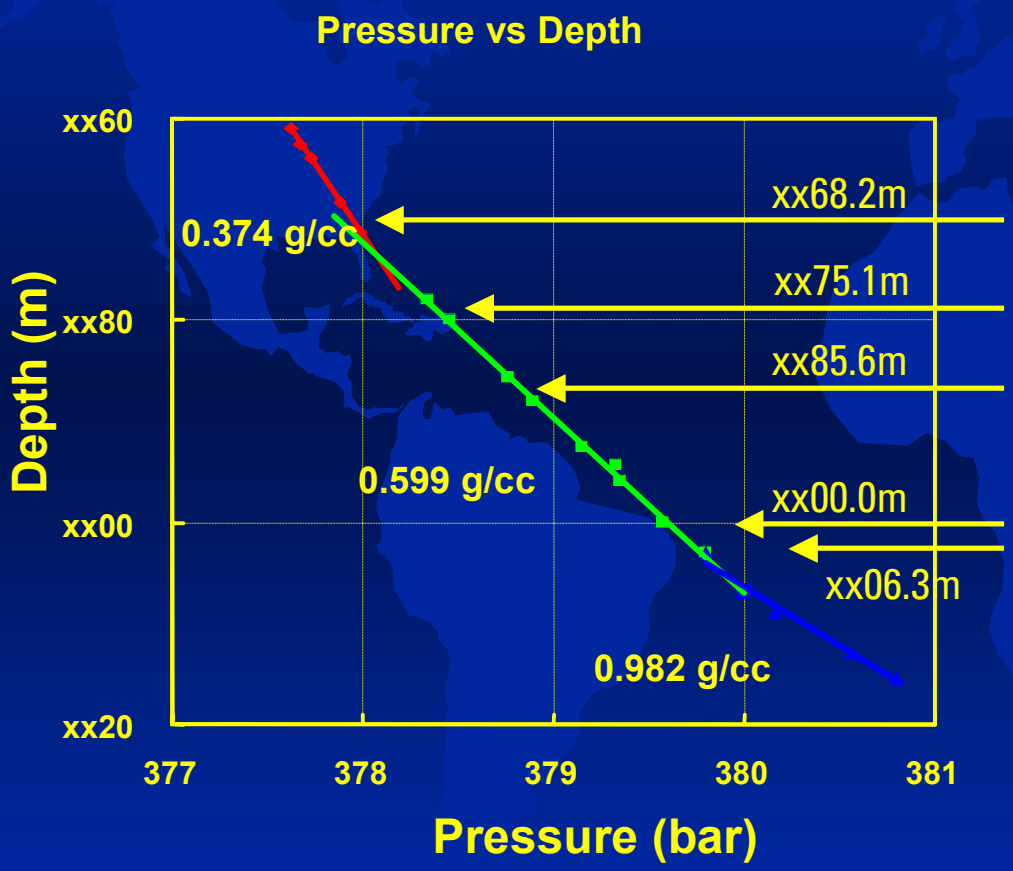


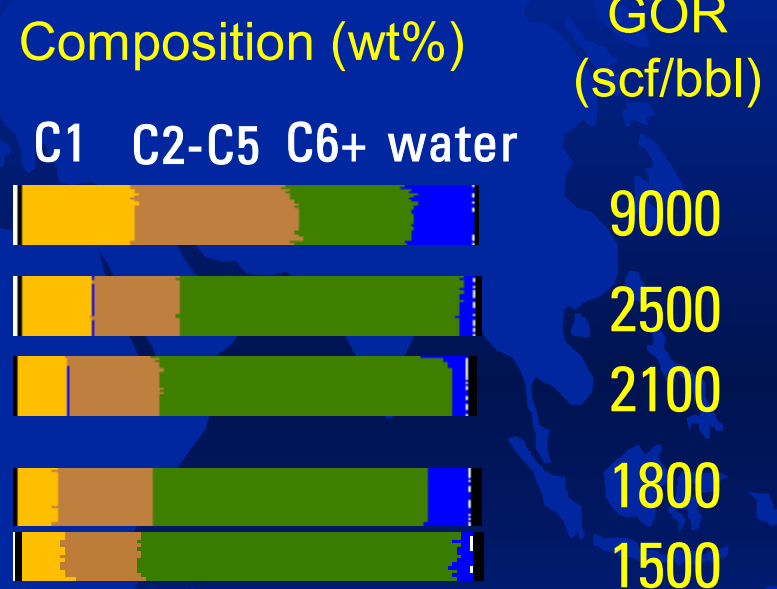
Optimizing flow geometry



Reservoir fluid gradient Statoil, North Sea

Fujisawa, Betancourt, Mullins, Torgersen, O'Keefe, Dong, K.O. Eriksen, SPE #89704, ATCE, (2004)





GOR (scf/bbl)

9000

2500

2100

1800

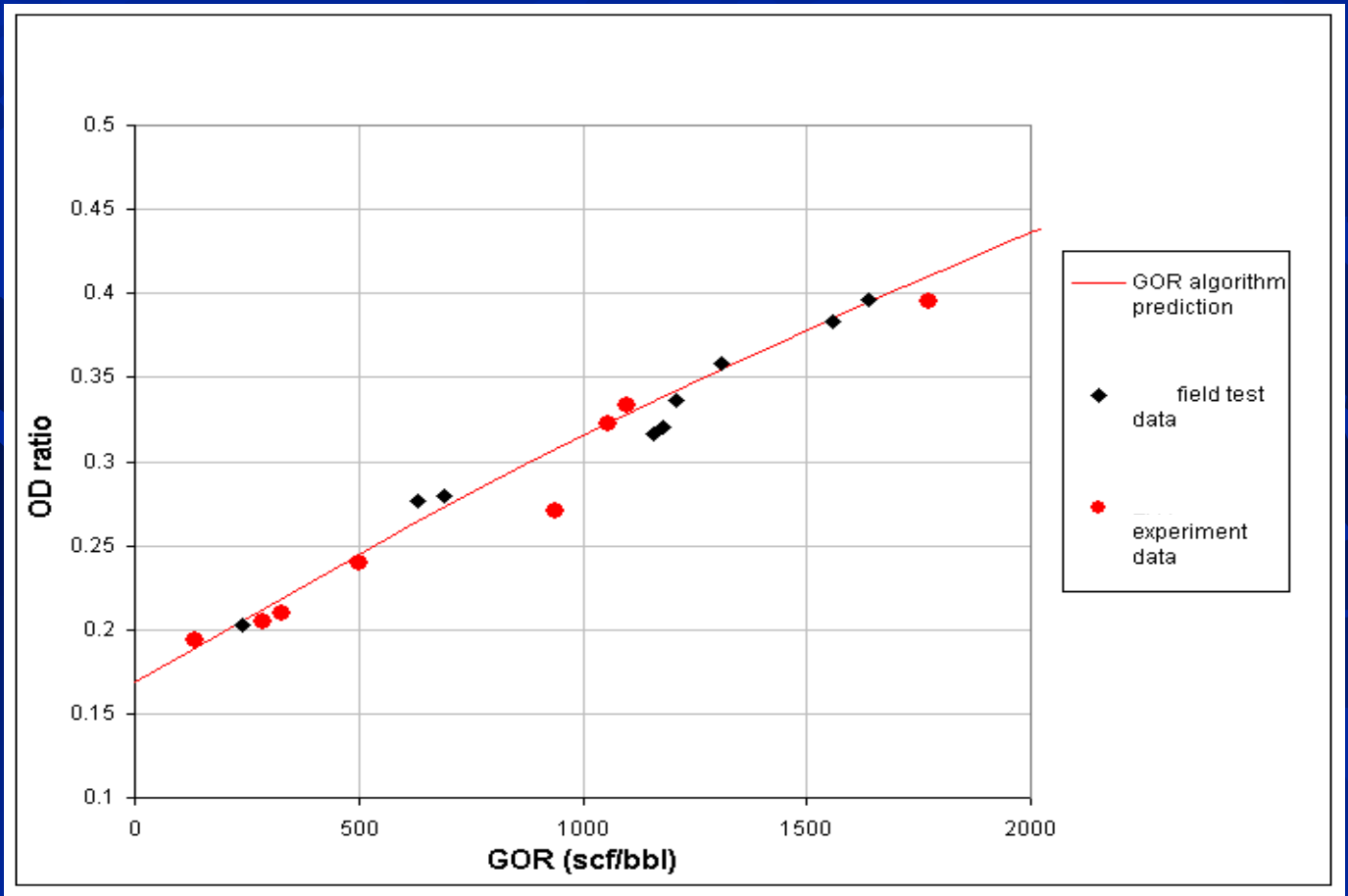
1500

Downhole fluid analysis

Current formation testers can give a few downhole fluid properties at each test point:

- **Gas Oil Ratio: 200 to 20,000 scf/stb (black oils to retrograde gas condensates)**
- **Fluid composition (wt % of certain components)**
- **Free gas and liquid dew detection**
- **Mud filtrate contamination (vol %)**
- **Water phase pH**
- **H_2S ?**

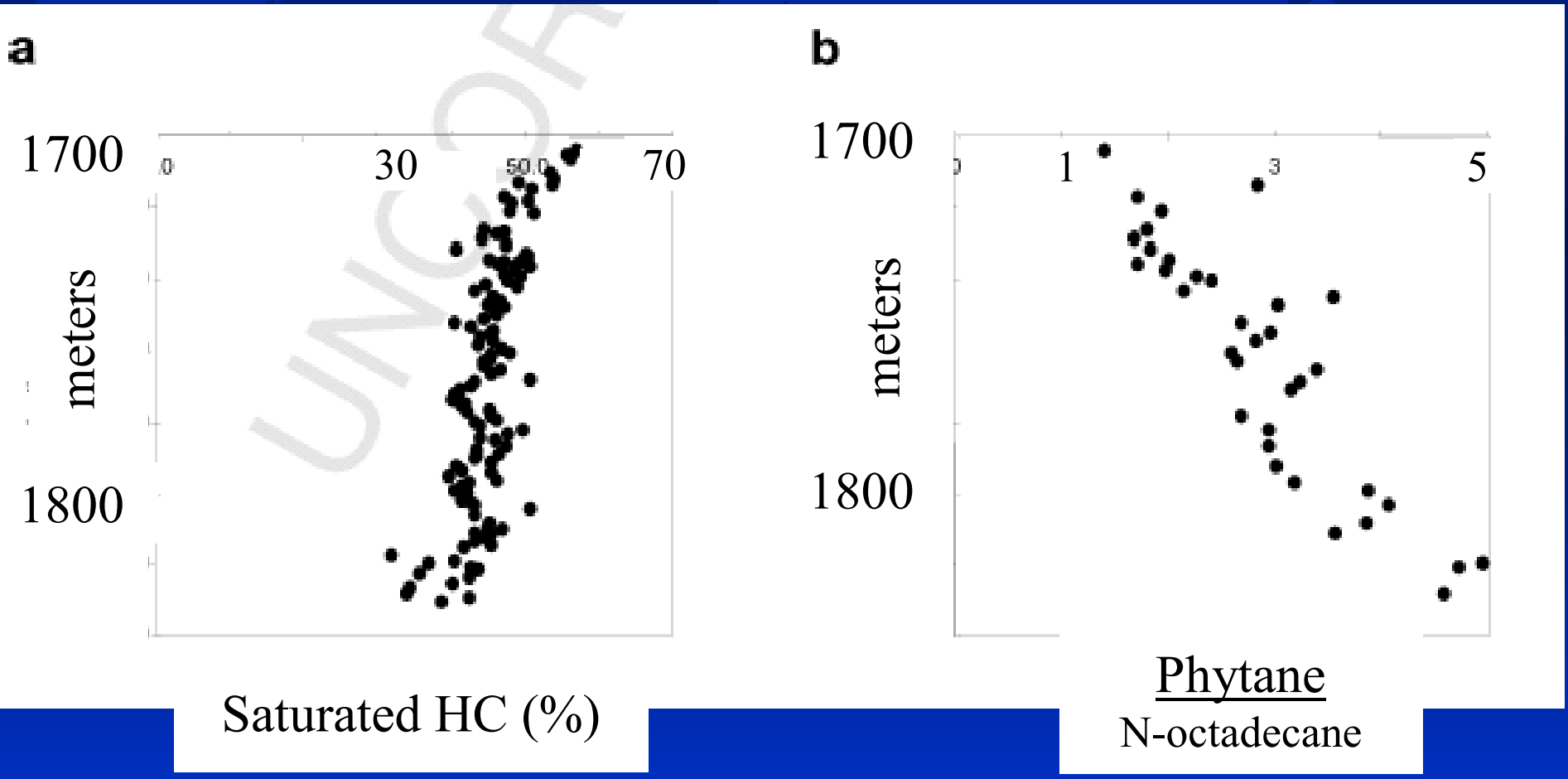
Downhole Gas-Oil Ratio



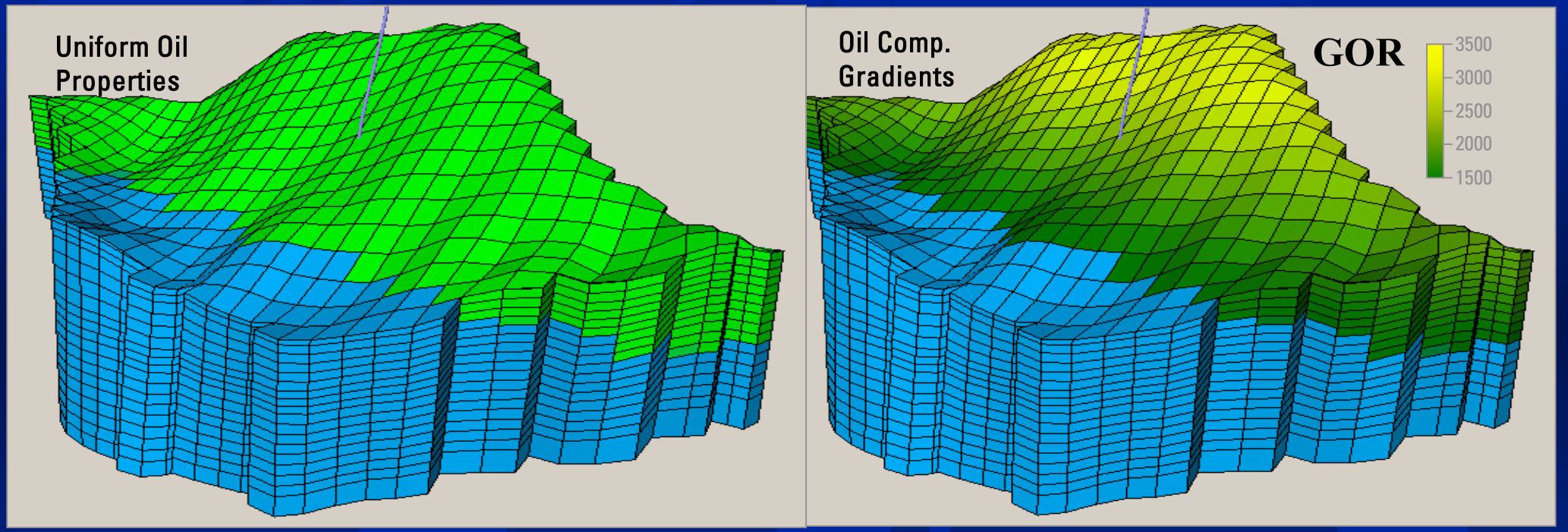
Fluid gradients from biodegradation

Liaohe Basin turbiditic sandstones of Eocene age at 1.8km depth. Tr ~ 65ºC
Prof. S.R. Larter, U. Newcastle on Tyne

Factor of 7 Variation in Viscosity 130 Meters



Reservoir Modeling: composition gradients



Optimize production strategy on right model.

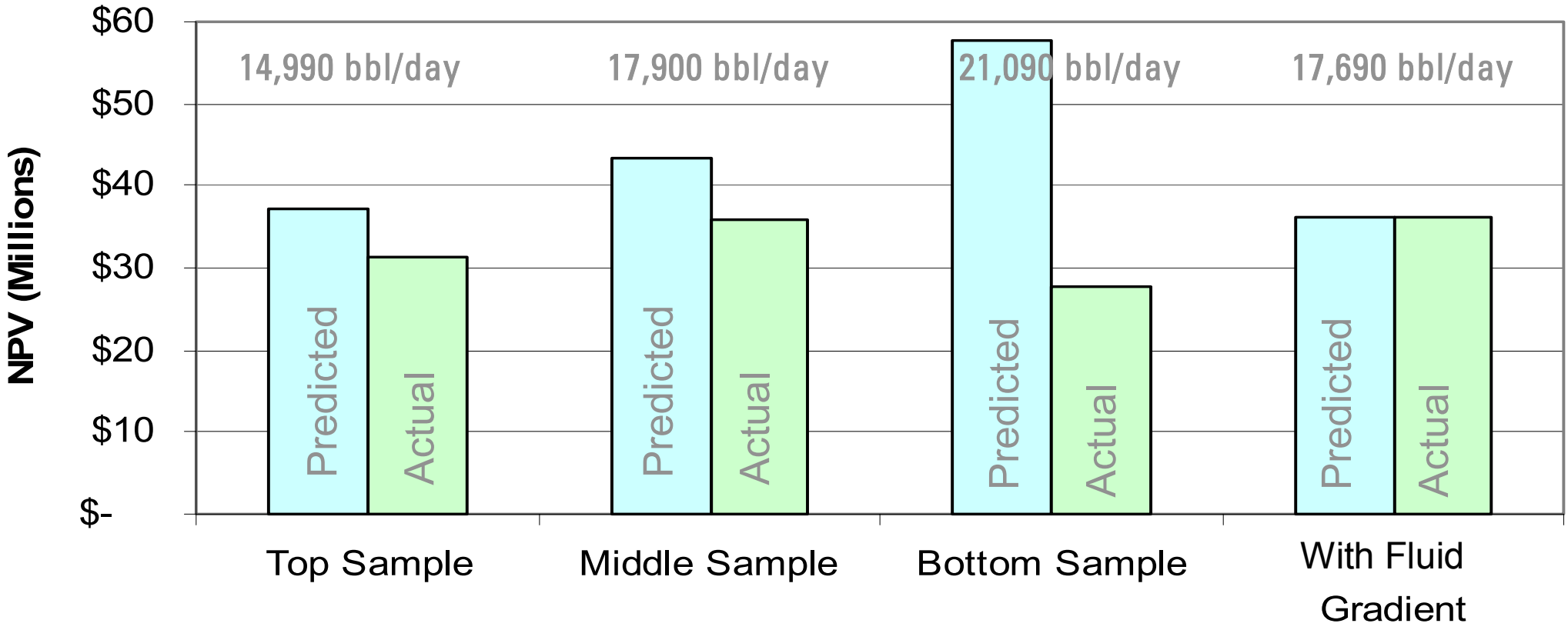
Size facilities properly.

Manage production below bubble point.

Understand time evolution.

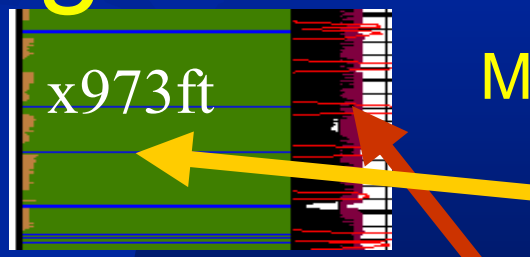
Courtesy of Peter Kaufmann- SDR

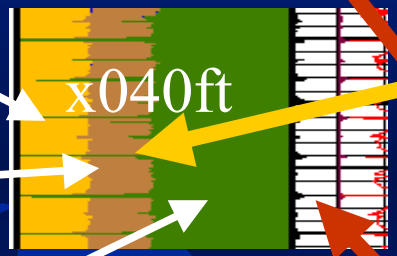
Financial summary- Synthetic case

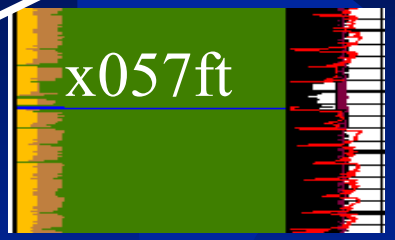


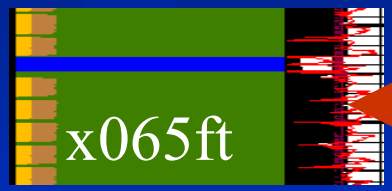
Courtesy of Peter Kaufmann- SDR

Downhole fluid analysis in production setting









CH_4

Other Gases

HC Liquids

Miscible Injection project and changing fluids

No gas here.

Gas Here.

Phase behavior time evolution seen in oil color.
Heavy end reduction with more gas.

Actual Oil Color

Downhole vs. lab results

GOR (scf/bbl)
(Downhole : Lab)

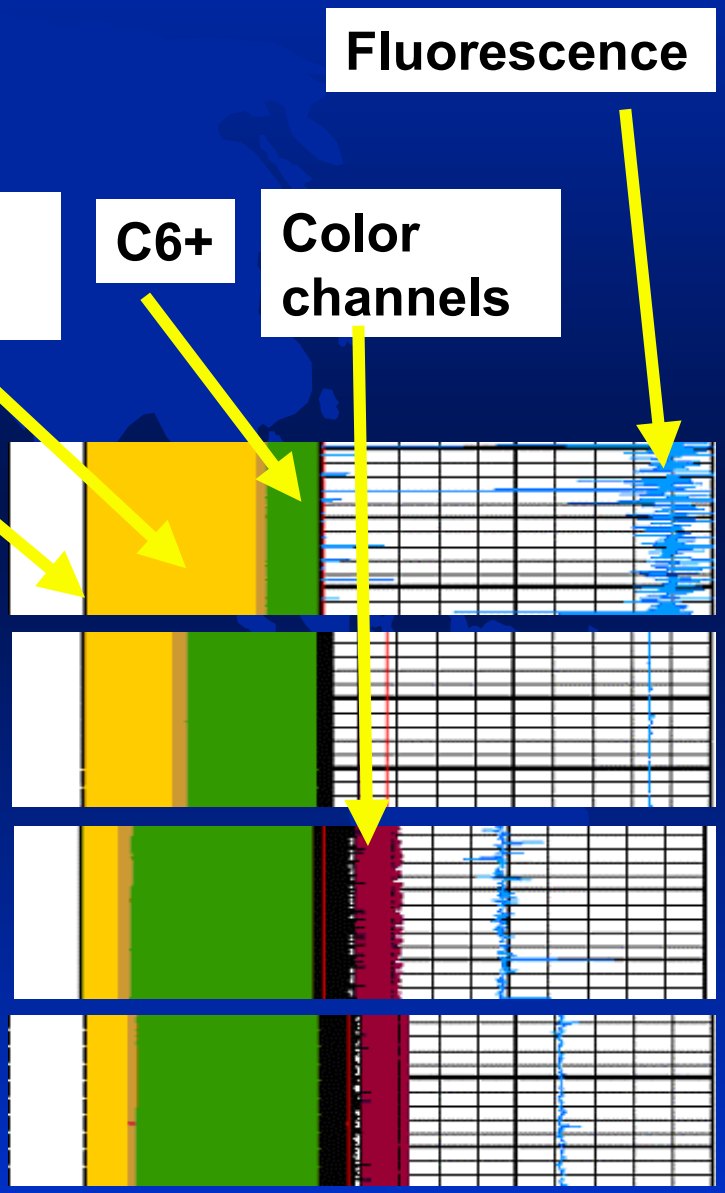
xx339.1 ft (20,400 : 26,000)

xx386.9 ft (4,500 : 5,000)

xx433.0 ft (1,600 : 930)

xx687.3 ft (1,500 : 1,400)

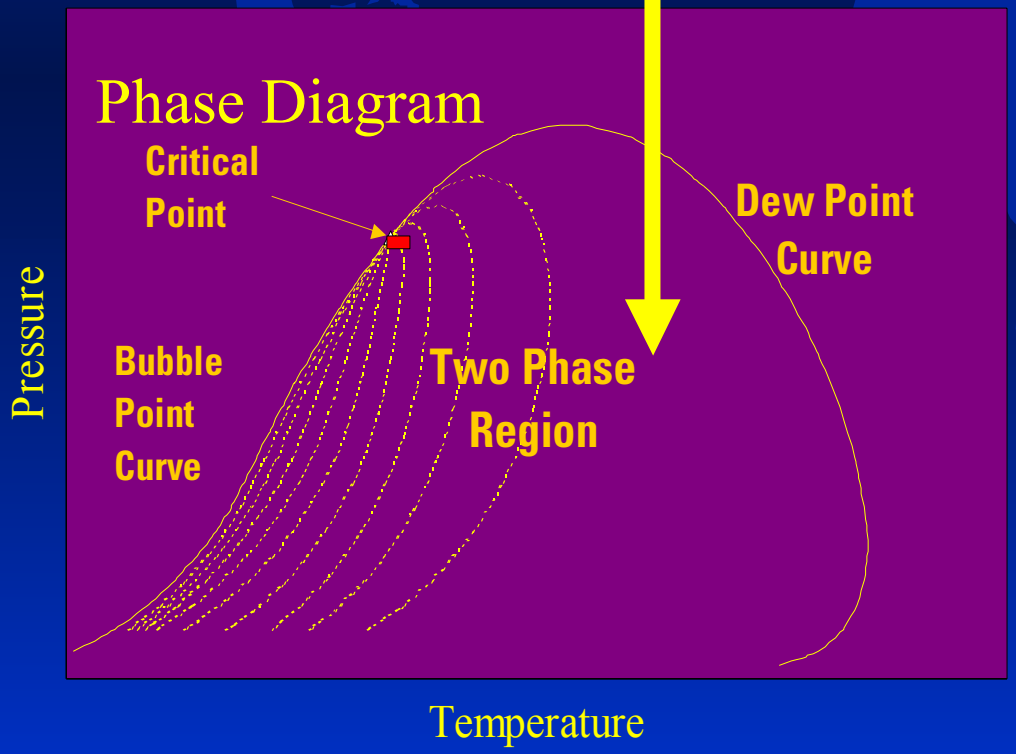
Downhole, Lab
Mostly agree
But problem here.



Downhole retrograde dew detection

Using Pump-Out as Phase Segregator

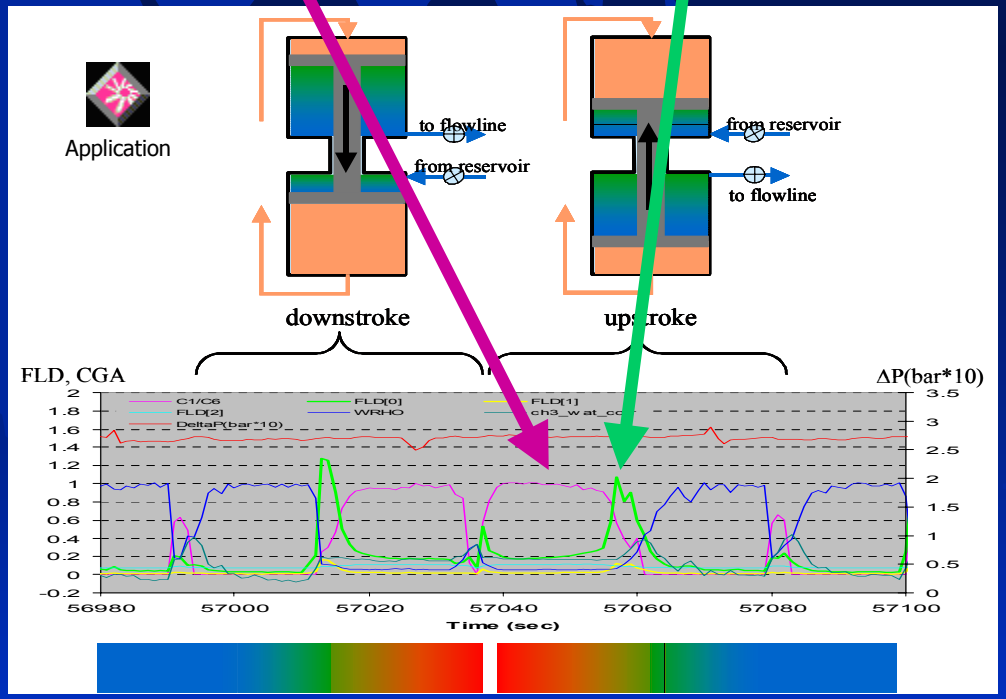
Dropped
Below
Dew Point



Log Data: Two HC Phases

C6 / C1

Fluorescence



Gradients and downhole fluid analysis

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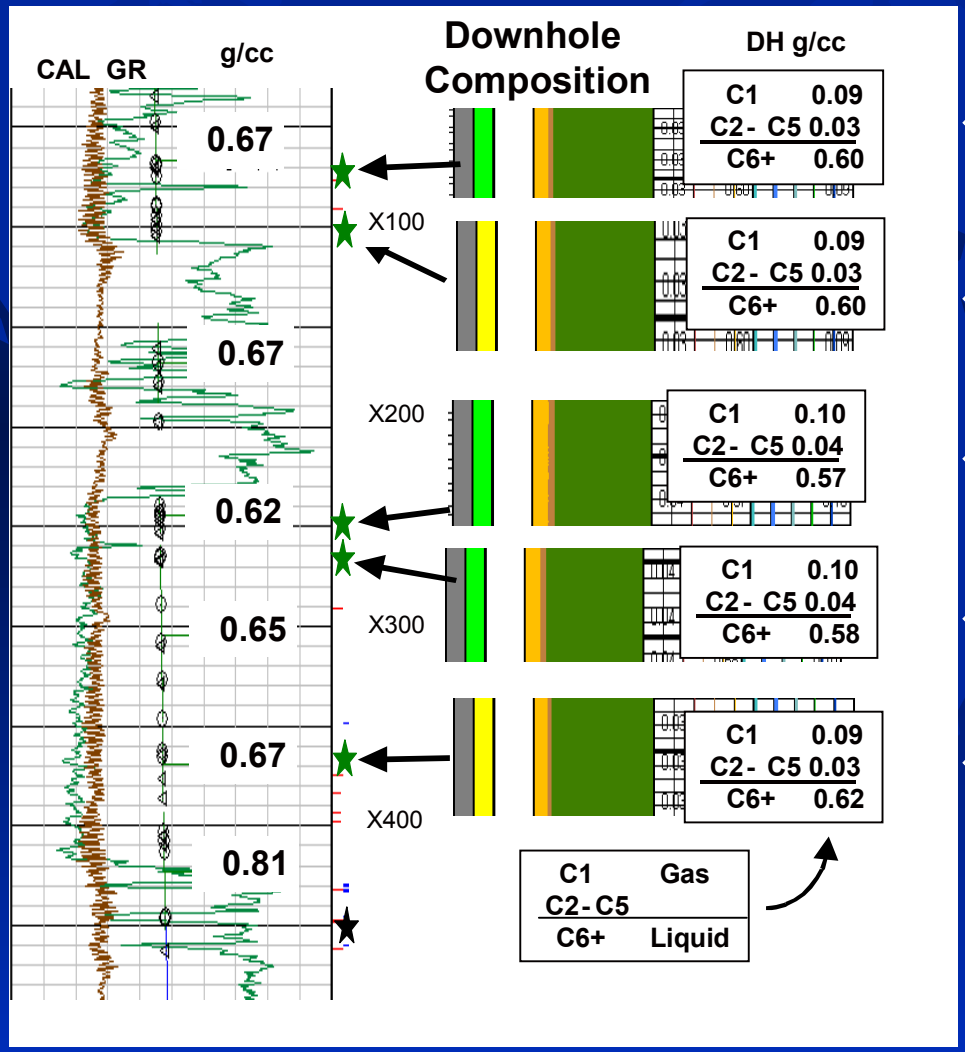


←Compare to 0.66 g/cc from Sample

←Compare to 0.66 g/cc from Sample

←Compare to 0.63 g/cc from Sample

←Compare to 0.64 g/cc from Sample

←Compare to 0.66 g/cc from Sample

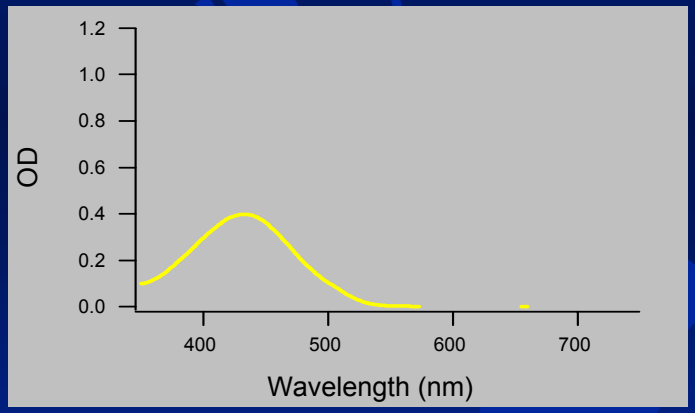
Formation tester downhole pH determination

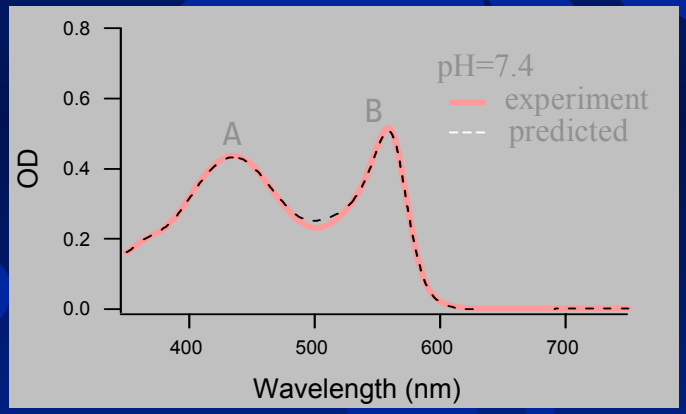
pH Sensitive Dye

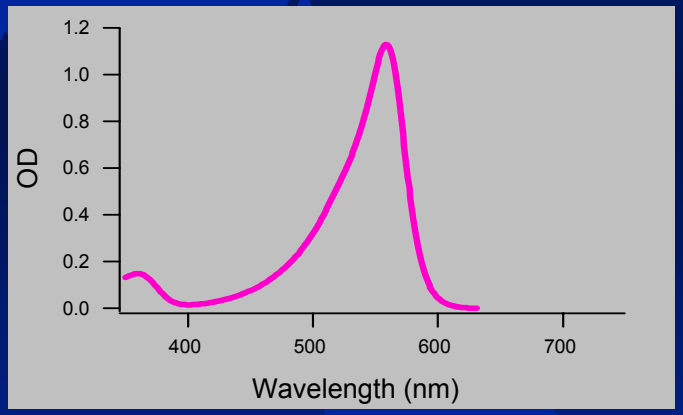
pH < 6
acid only

6 <pH < 9
acid-base mixture

pH > 9
base only







Accuracy ~ 0.1 unit
Range pH = 4 to 9

Downhole water analysis:early understanding of scale problems

LAB pH: Lost gas, solids. ΔpH ~ +/-1

H_2S detection

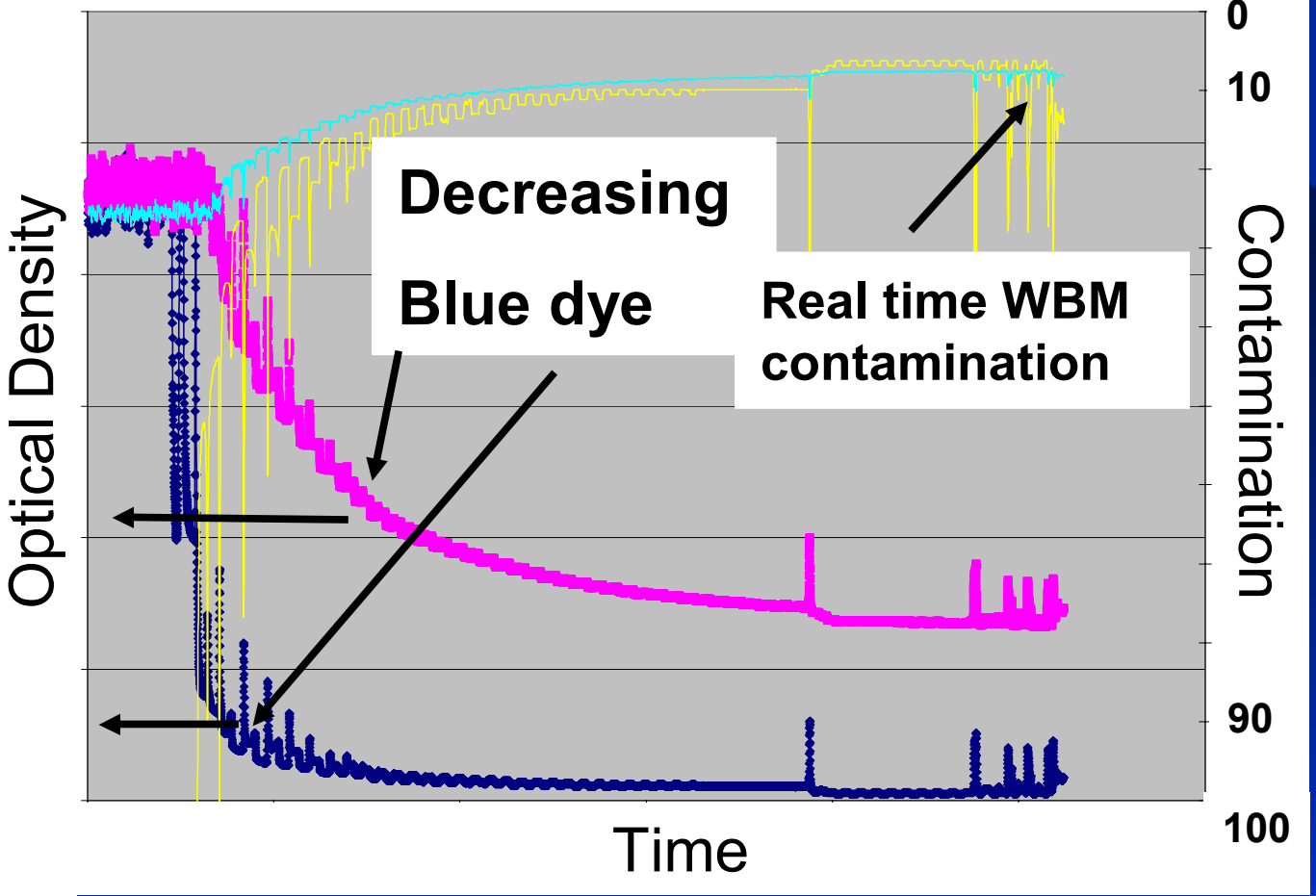
Real-Time H_2S detection in fluids since all metals react with H_2S

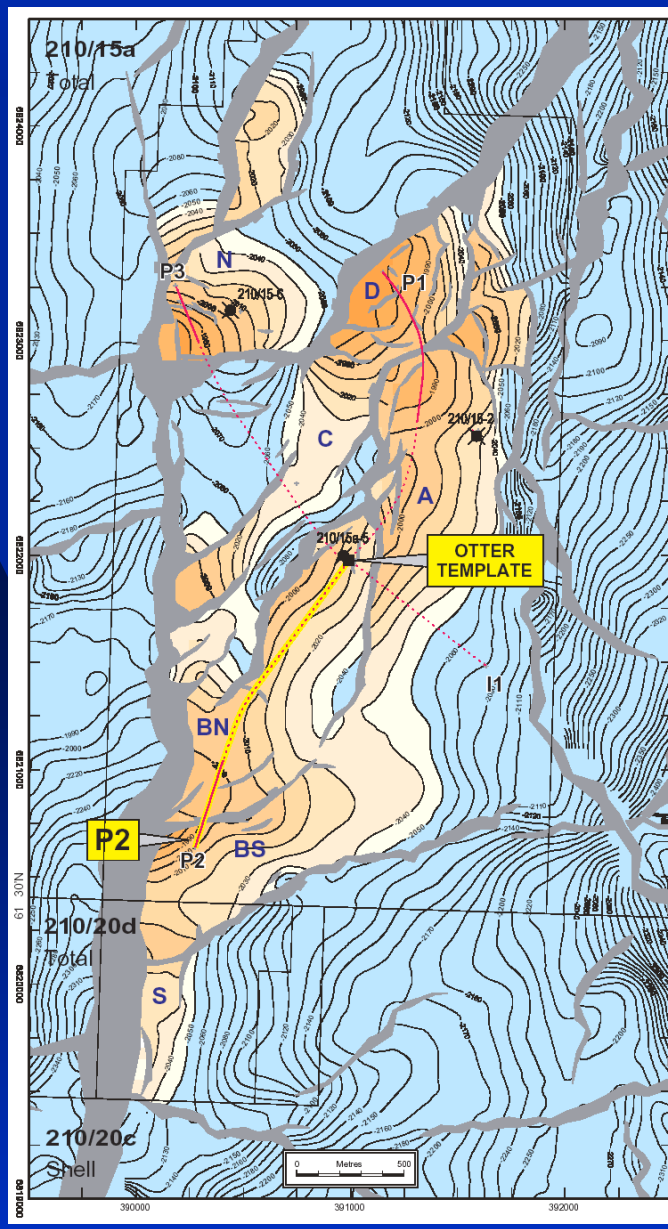
H_2S could then be missed in sample or underestimated

Work on real time sensor ongoing, current method uses H_2S sensitive metal coupons

Water sampling in WBM

SPE 88637-North Sea





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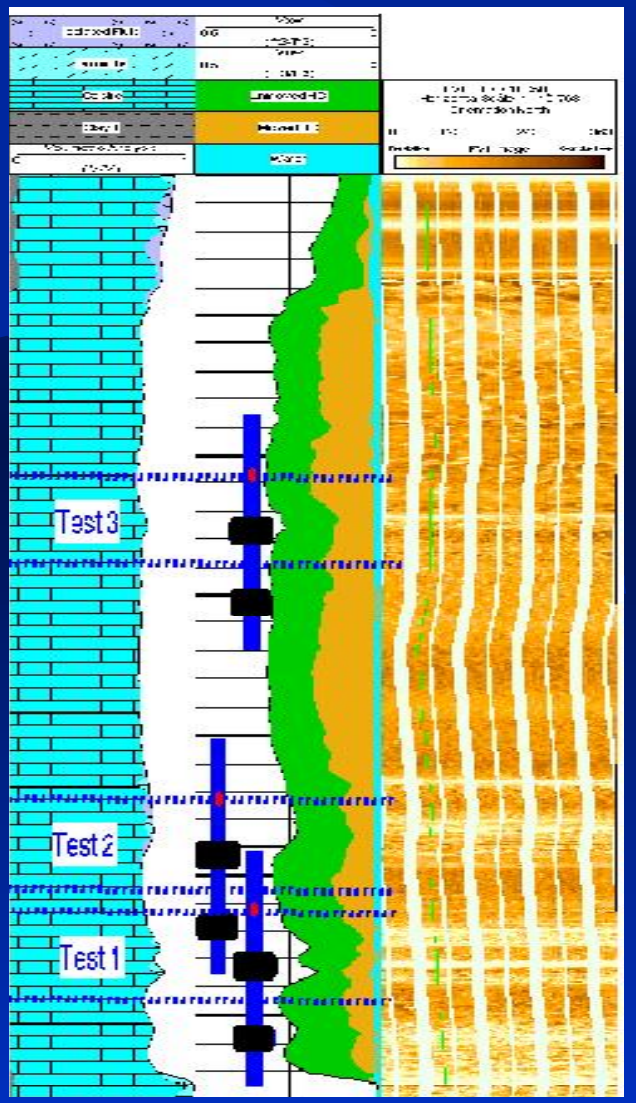
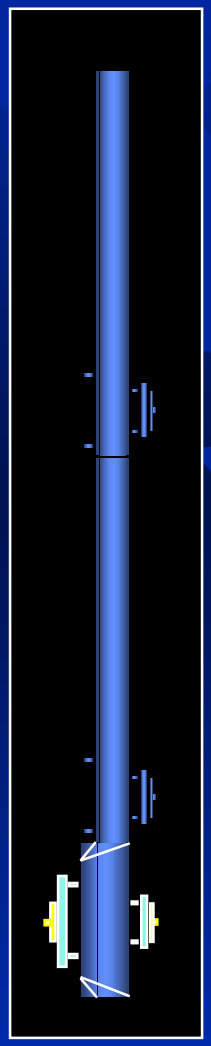
Permeability and permeability anisotropy

Interval Pressure Transient Tests (IPTT) are conducted with various combinations of probes and/or dual packer.

Objective is to obtain permeability and anisotropy in "10's" of feet around the well.



Basic Principles



For an infinite homogeneous-anisotropic medium and with constant rate:

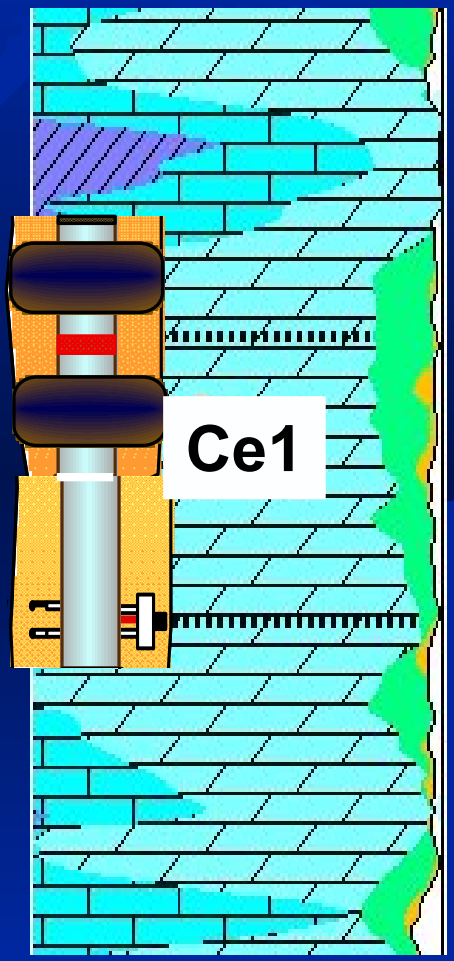
The response at the vertical probe is given by:

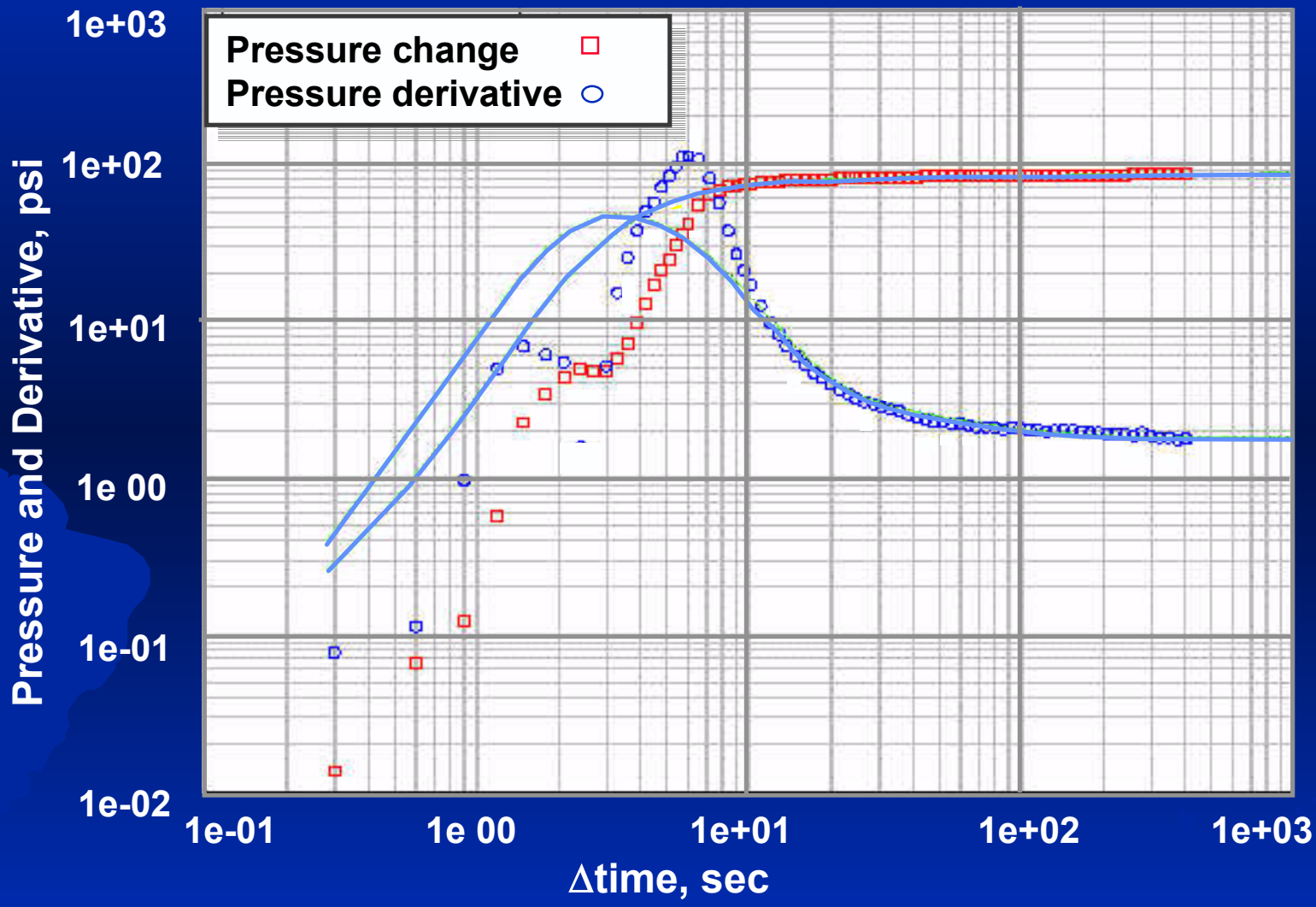
$$\Delta p_v = 460.42 \frac{q\mu}{z_p k_h}\left[\Omega_v - \frac{1}{\sqrt{\pi \nu_v t}}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The response at the horizontal probe is given by:

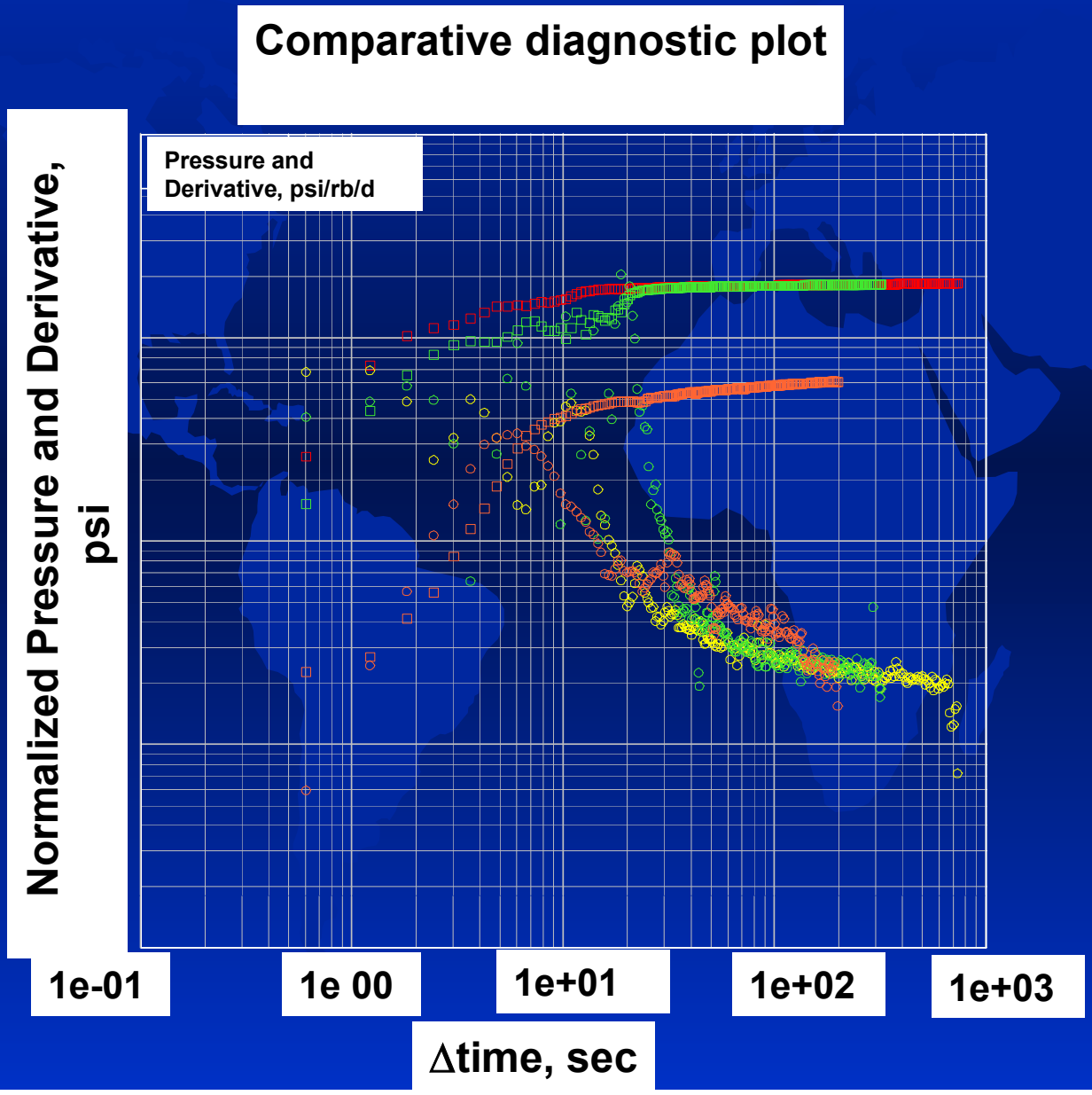
$$\Delta p_h = 230.21 \frac{q\mu}{r_w \sqrt{k_h\, k_v}}\left[\Omega_h - \frac{2}{\sqrt{\pi \nu_h t}}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Transient testing-carbonates





Transient testing-loose sand

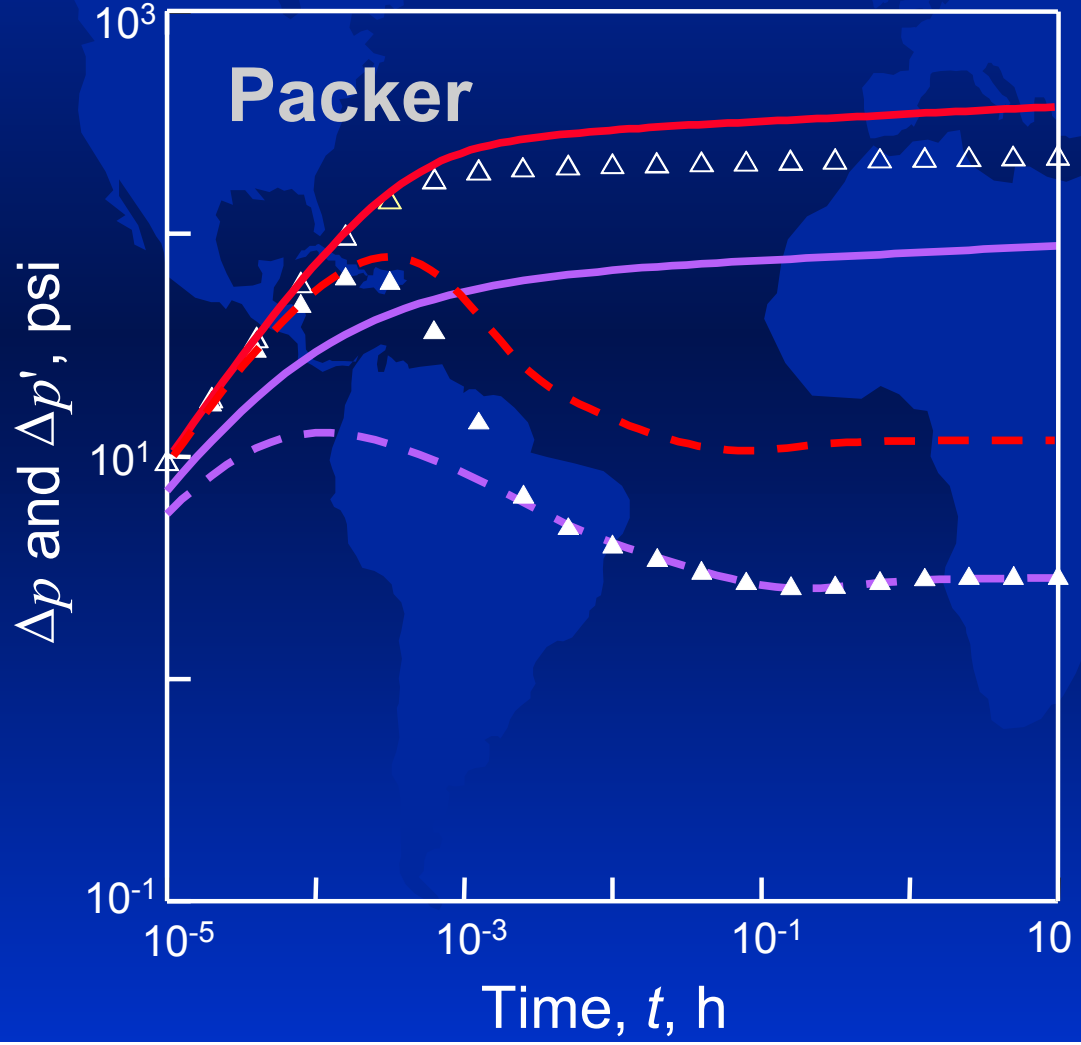


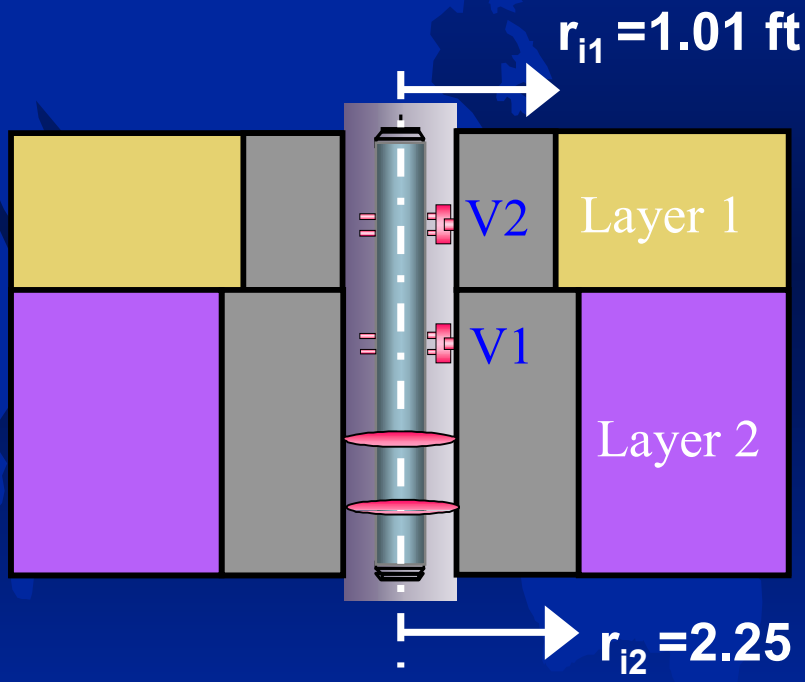
Kh =~ kv= 1000 md

(loose sand, 100 cp oil)

Effects of Invasion

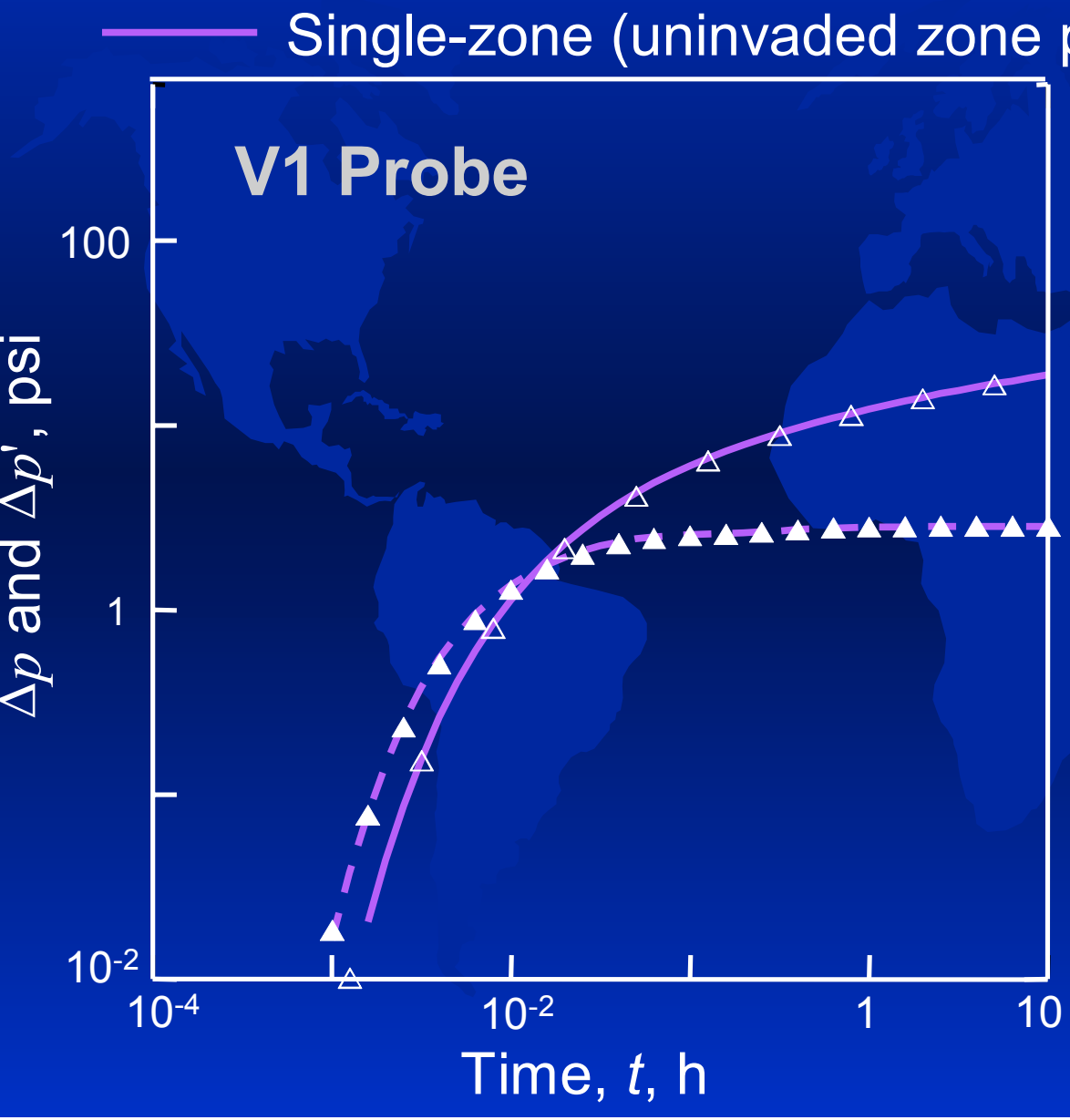
Single-zone (uninvaded zone properties)
Single-zone (invaded zone properties)

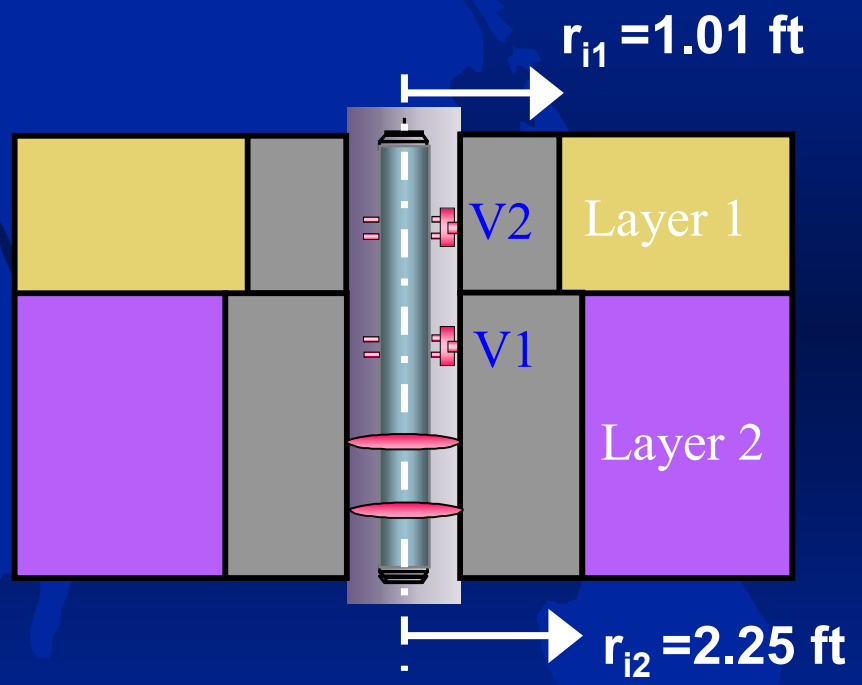




Two-Layer, Packer-Probe SPE 84093

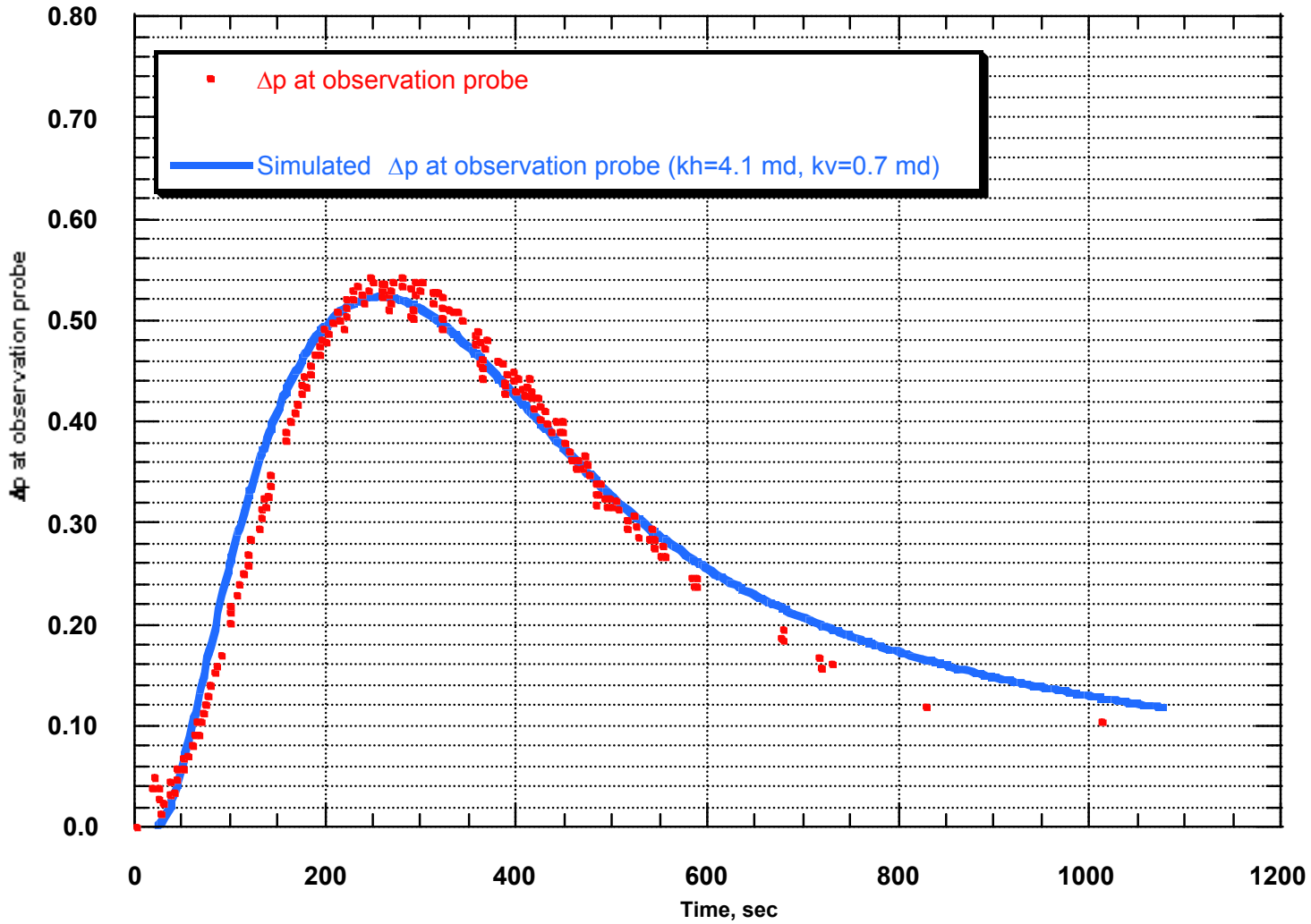
Effects of Invasion





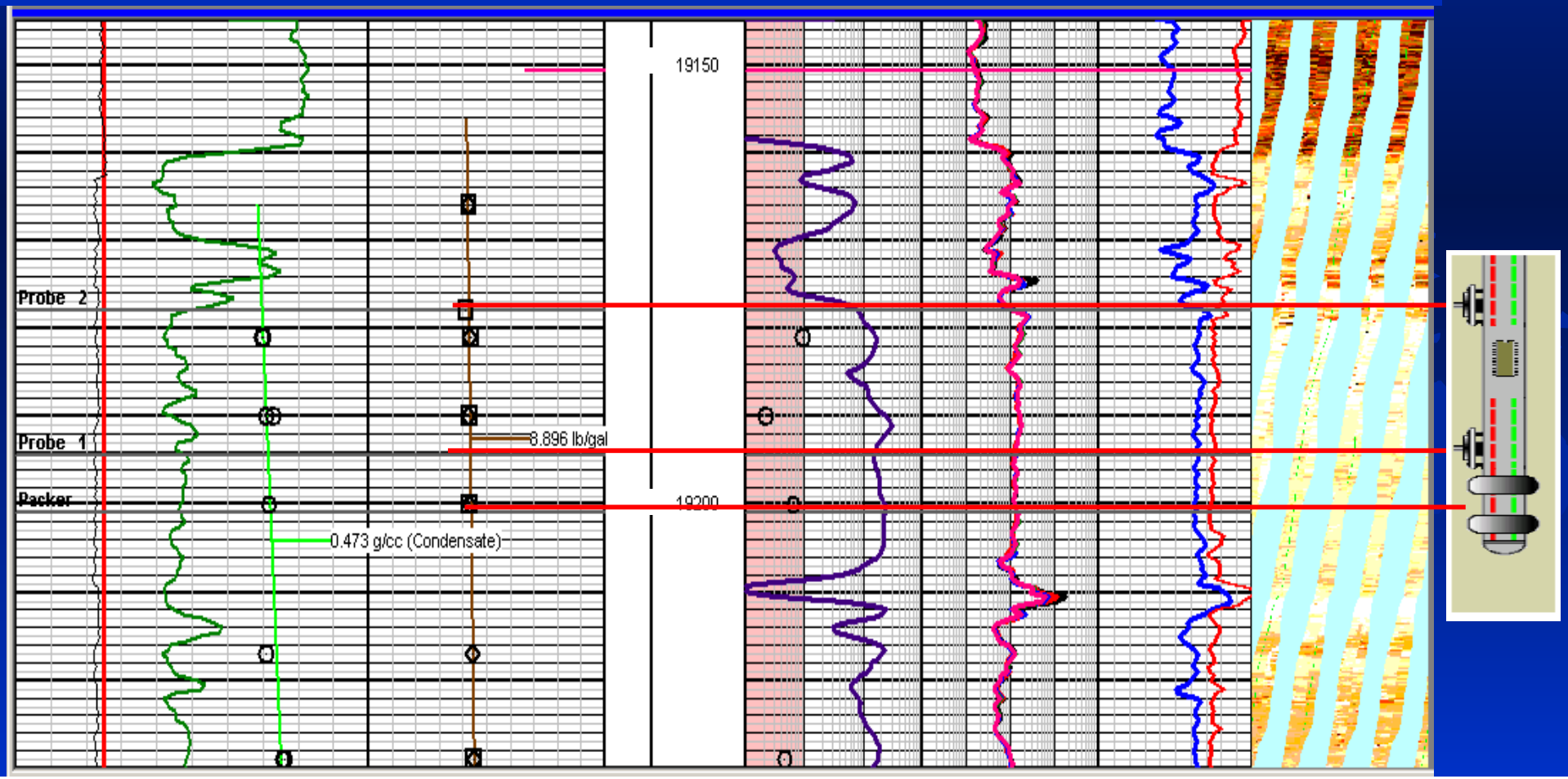
Two-Layer, Packer-Probe SPE 84093

Retrograde Gas - IPTT test with probes

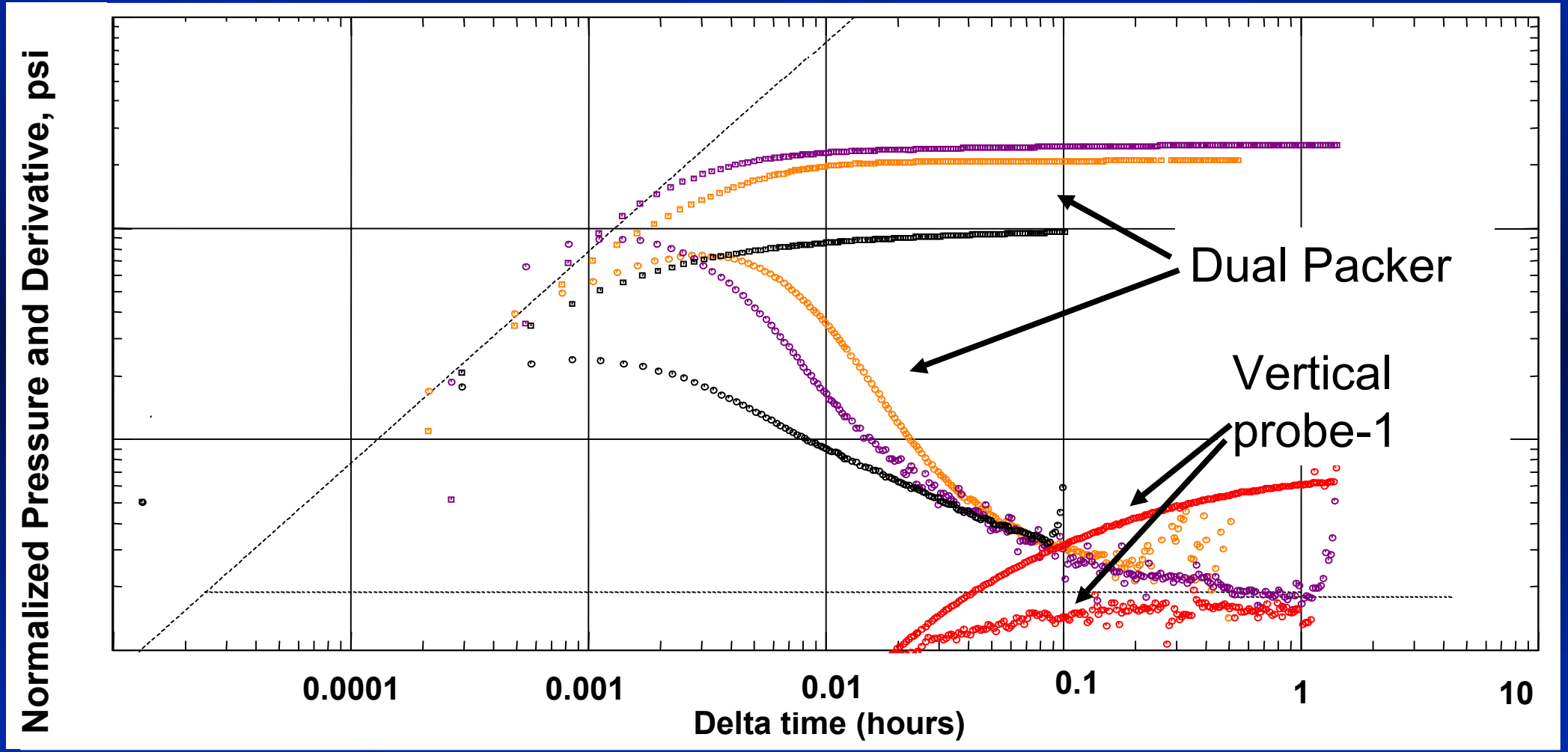


Objective: kv/kh for deviated well performance

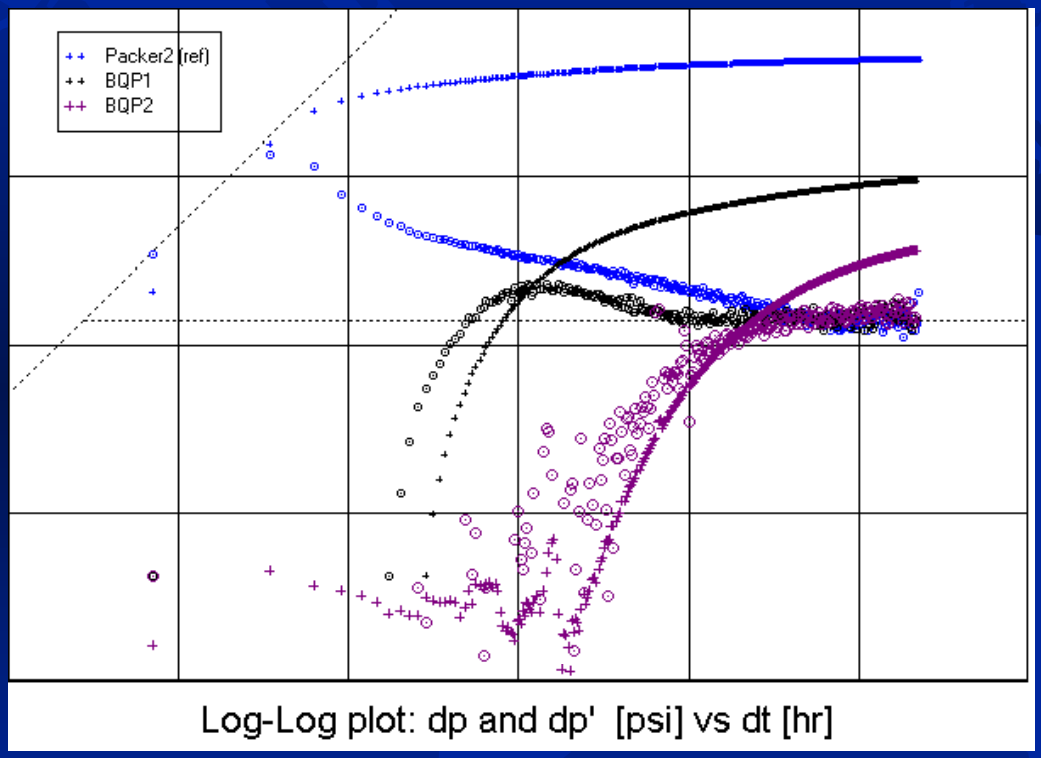
Gulf of Mexico
Formation tester-transient testing (OBM)



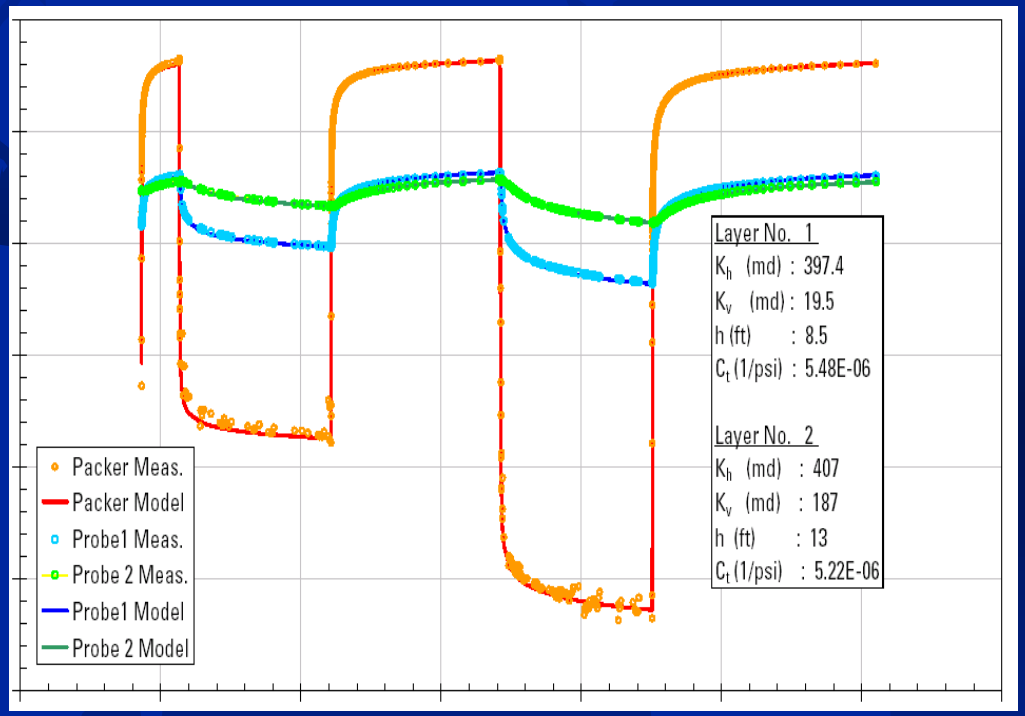
Rate normalized pressure and derivatives



GoM- Testing with dual packer and two probes

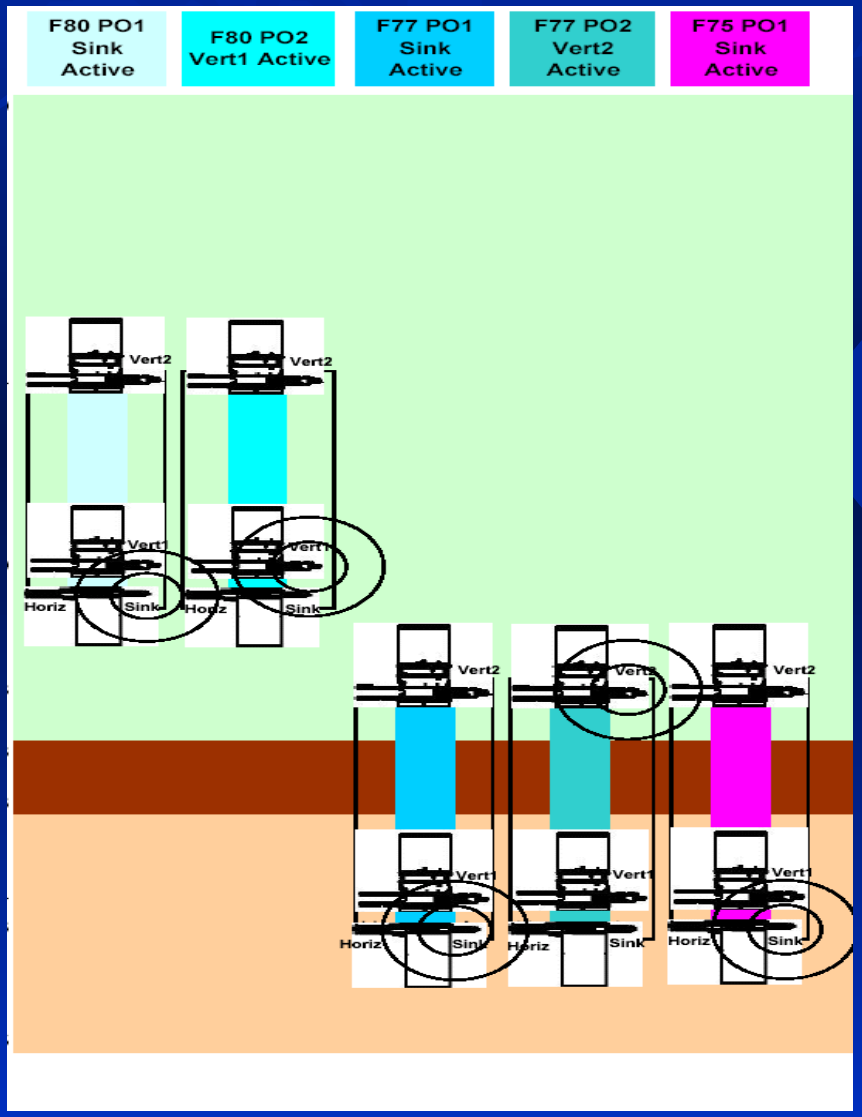


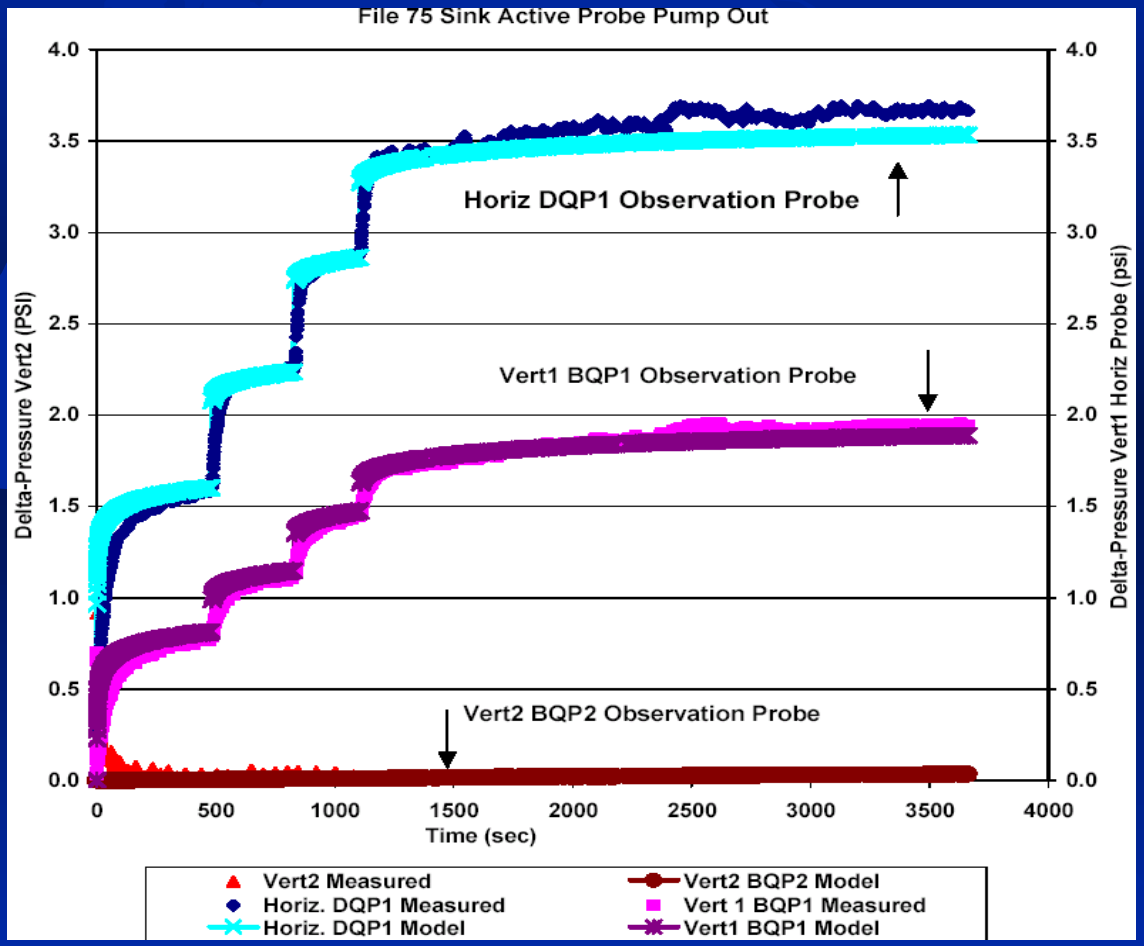
Log-Log plot: dp and dp' [psi] vs dt [hr]



SPE94708-Oct. 2005

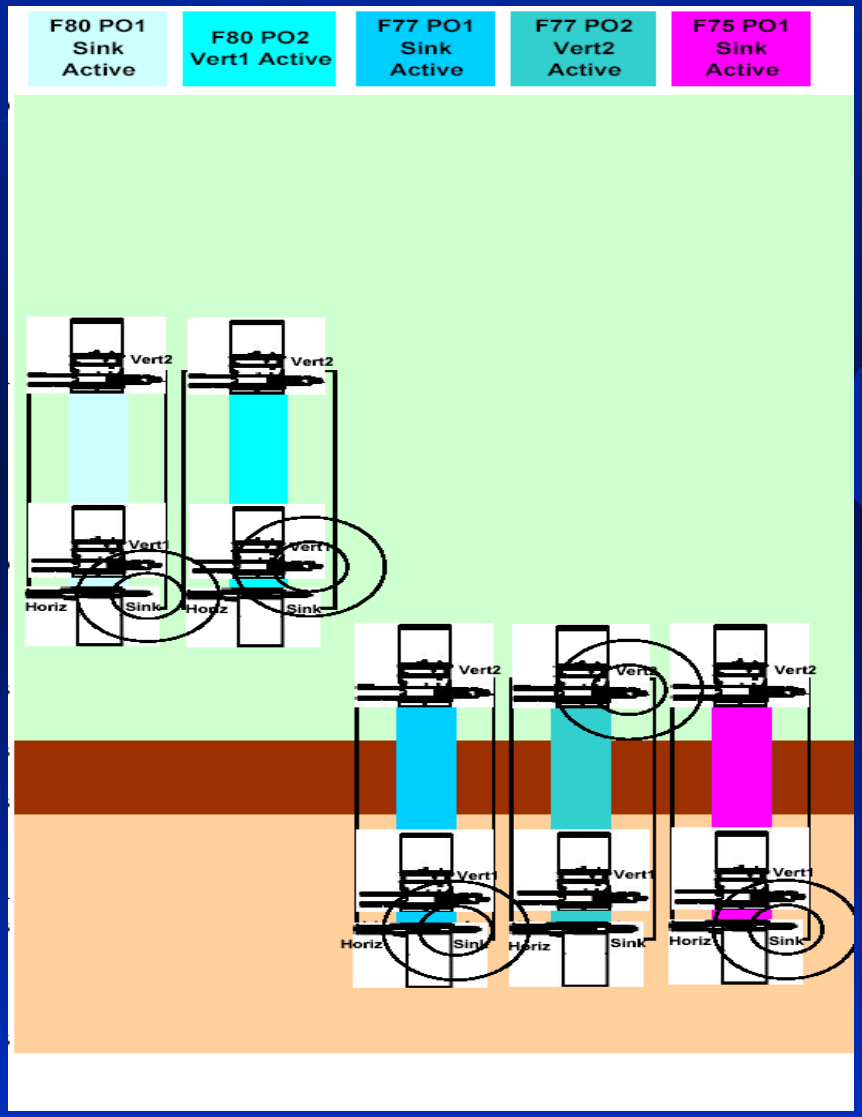
GoM Testing with dual probe and two single probes in a layered reservoir

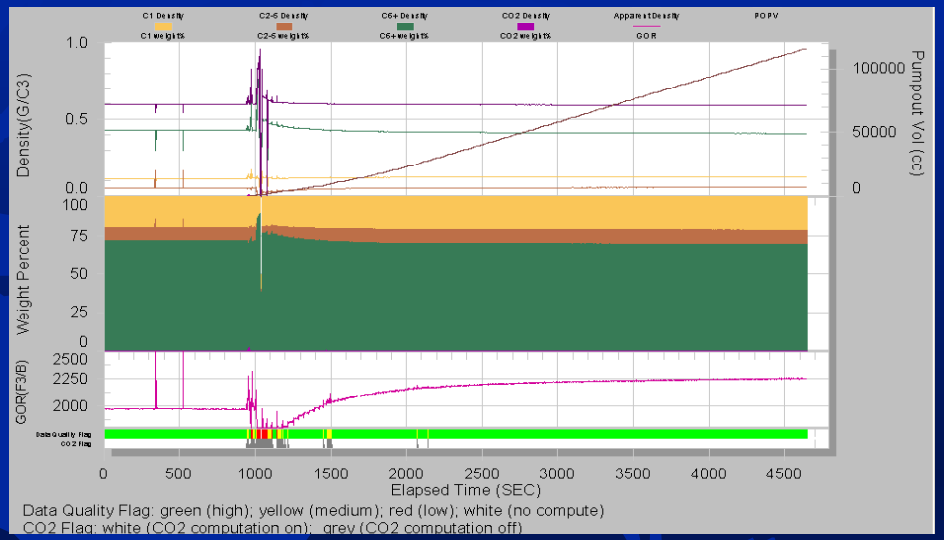


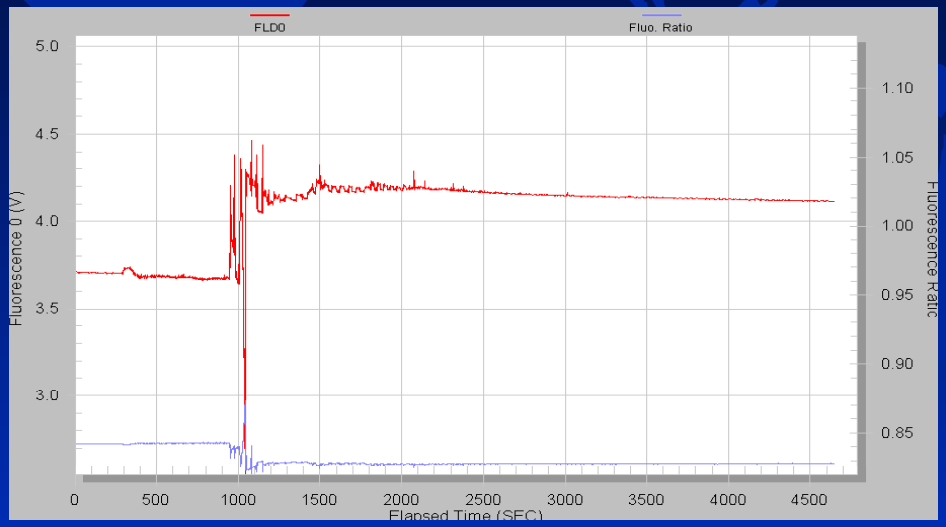


SPE94708-Oct. 2005

GoM Testing with dual probe and two single probes in a layered reservoir



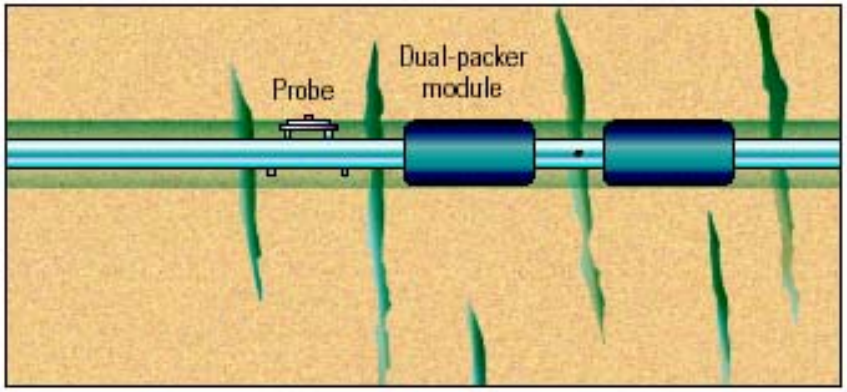


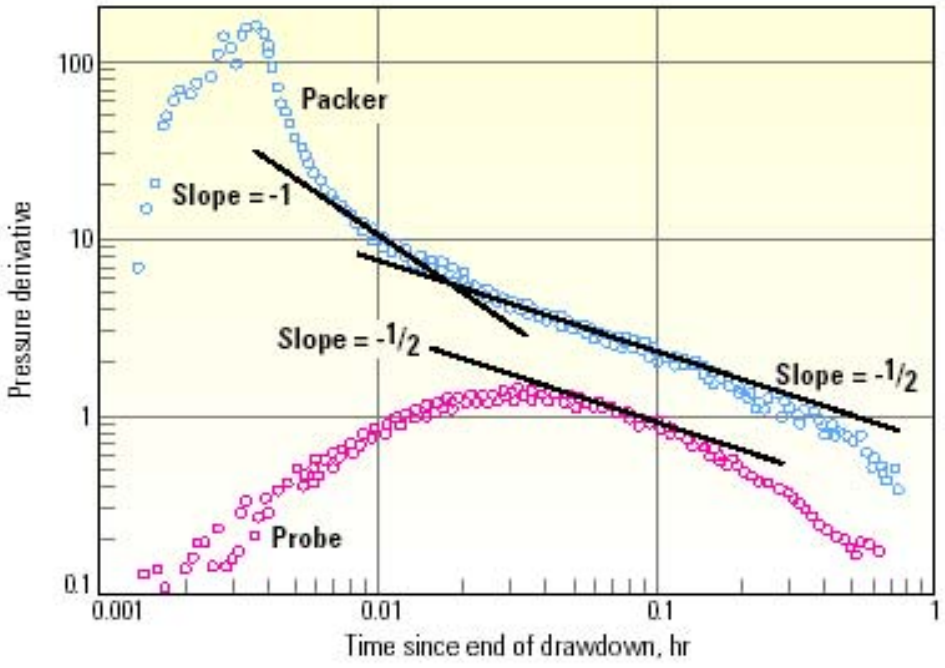


SPE94708-Oct. 2005

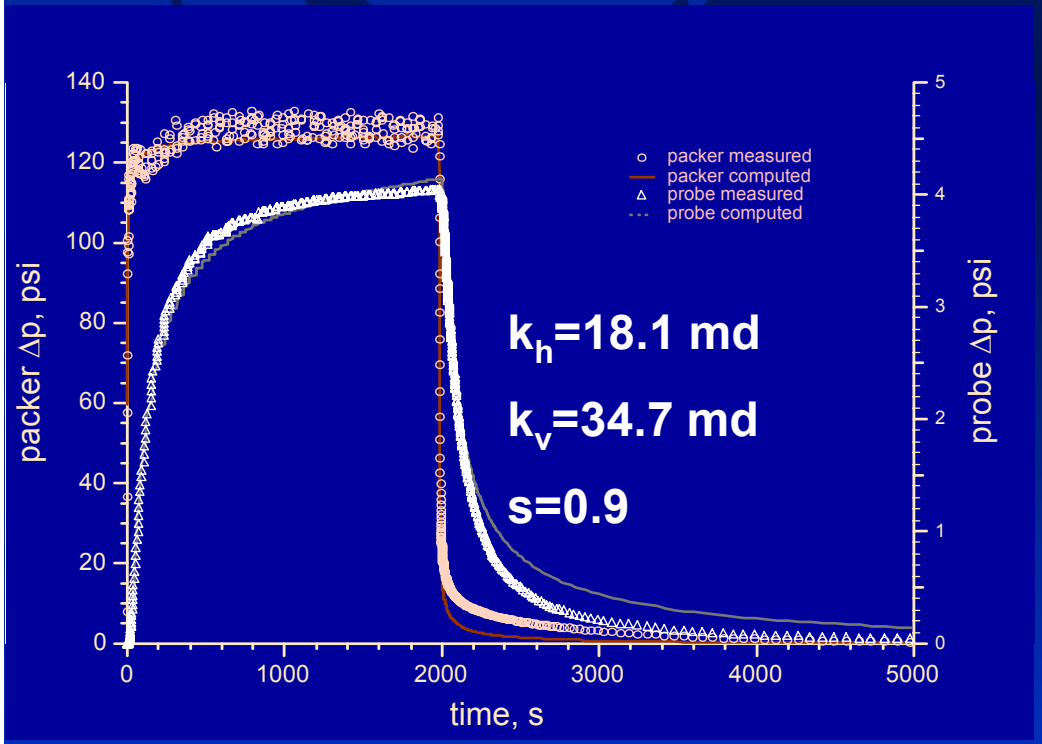
Horizontal wells

Packer-probe test with fractures- SPE68137





Interval tests conducted show that the fractures are not highly conductive, both packer and probe showing spherical flow



Productivity Index for a circular reservoir

$$PI = \frac{q}{p_e - p_{wf}} = \frac{2kh\pi}{\mu(\ln\frac{r_e}{r_w} - \frac{1}{2} + s)}$$

We know:

p_e **(from probes, packer pressures)**

h **(from logs)**

r_w **(bit size)**

k **(from IPTT's, also we identify nearby heterogeneities)**

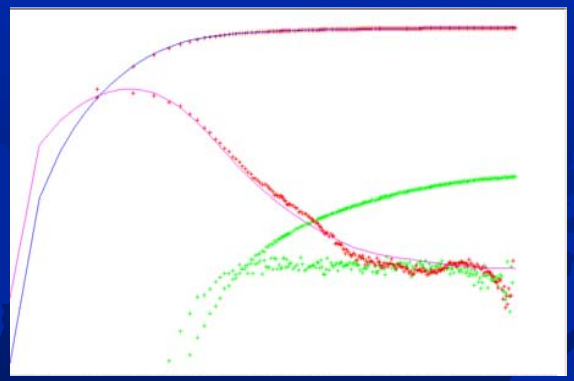
We do not know:

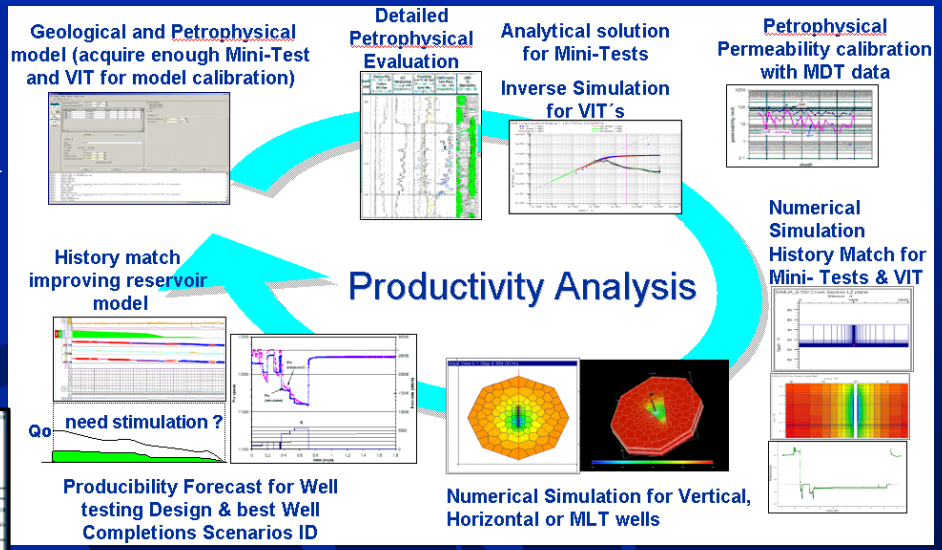
final total skin, *s* = *(perforation charges, phasing, density, kv/kh, open hole damage and damage zone thickness, perforated interval length and position, non-darcy flow, formation strength and insitu-stress,…)*

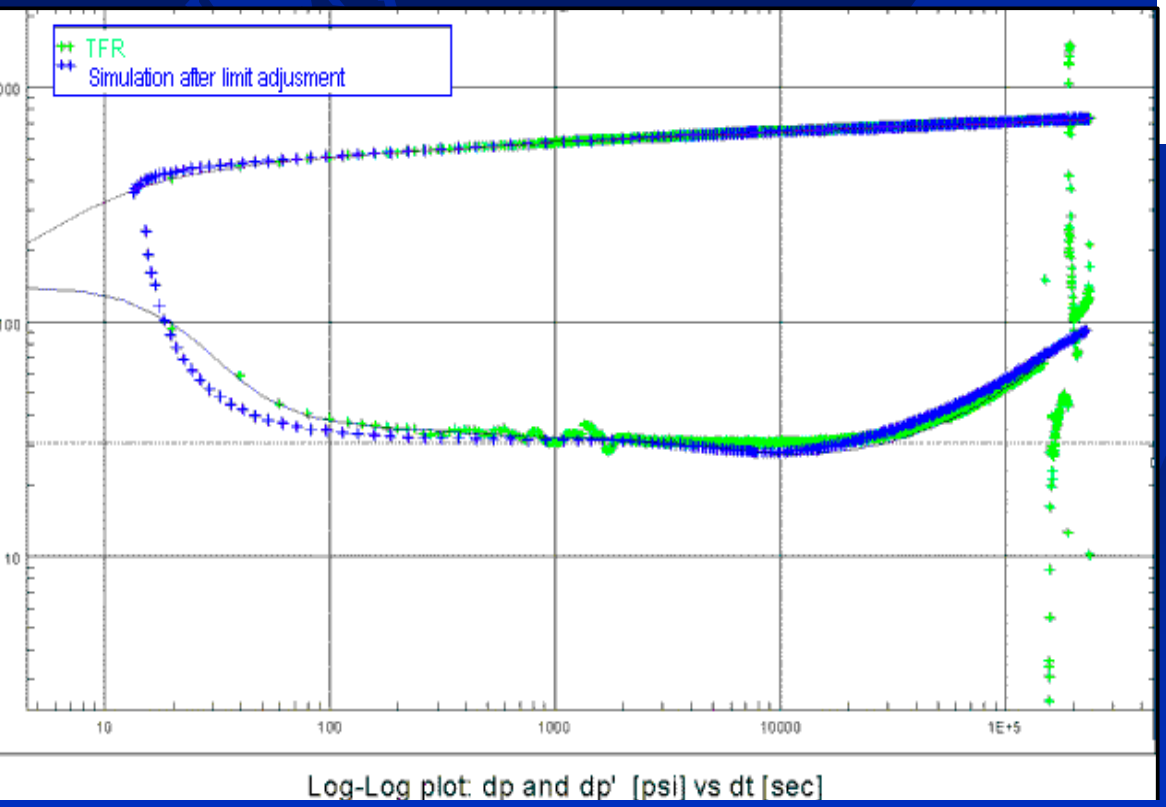
re ***(outer boundary)***

Formation tester IPTT and DST-Brasil

Analysis of individual IPTT's







Paper IBP 20104 by Jesus Canas *et al.*,

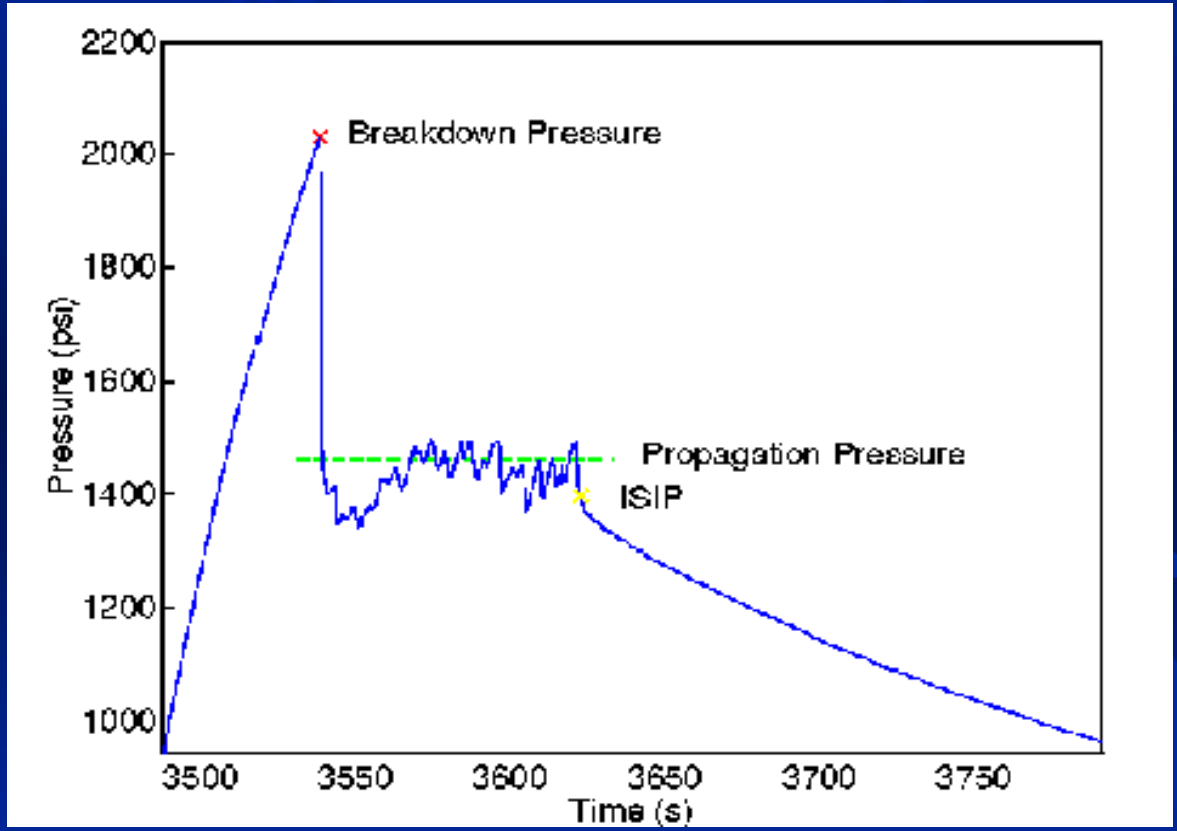
Rio Oil and Gas-2004

Formation Testing:
Where Are We After 15 Years with Advanced Wireline Tools?

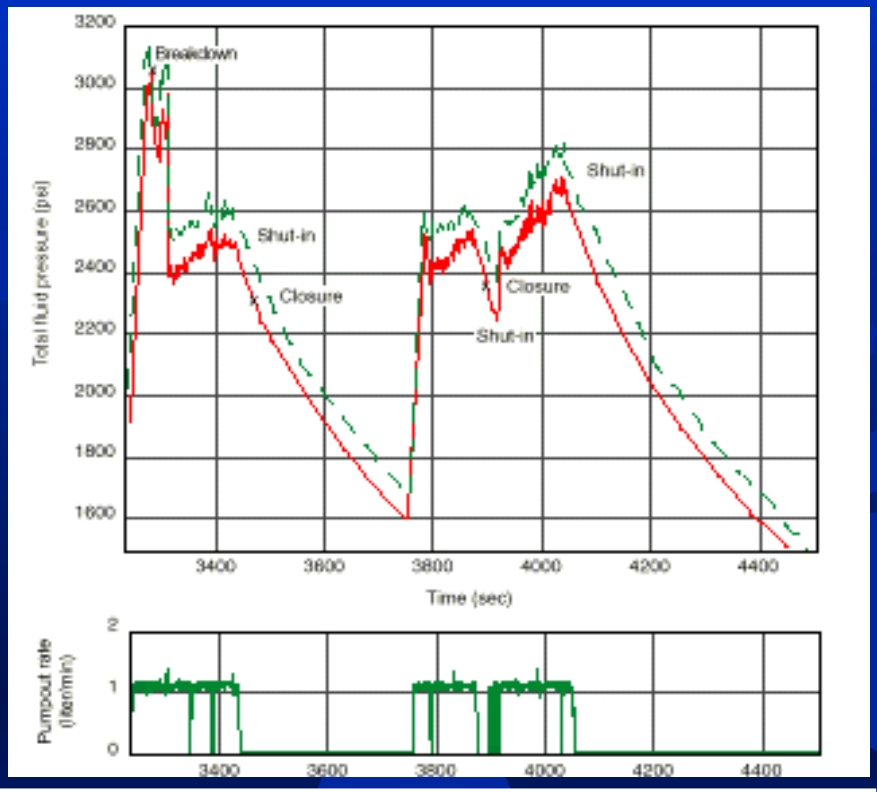
- Pressures
- Sampling and Downhole Fluid Analysis
- Transient Testing (IPTT)
- In-Situ Stress Testing

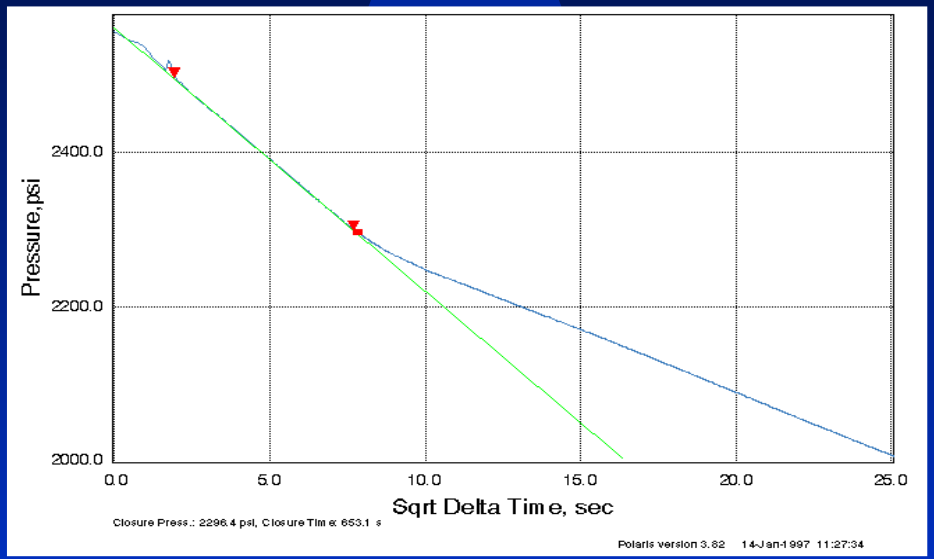
In situ stress testing (micro fracturing)

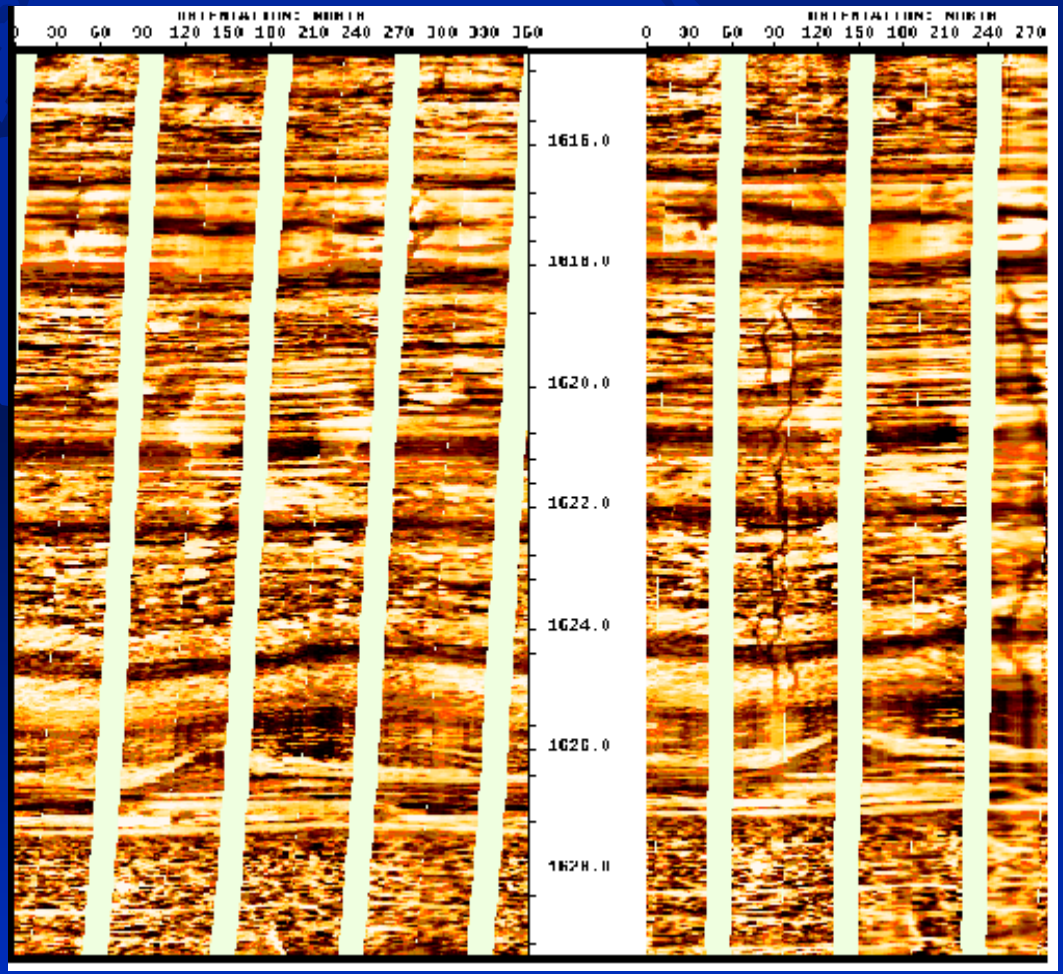
Mostly Conducted using packer type formation testers



In-situ stress testing
Magnitude and orientation







Formation Testing: Conclusions

Where Are We After 15 Years with Advanced Wireline Tools?

Pressure measurements: Moving towards tighter rocks with faster surveys and now possible behind casing

Sampling and Fluids: Sampling techniques/strings getting very complex. Fluid analysis is moving downhole, with little or no contamination

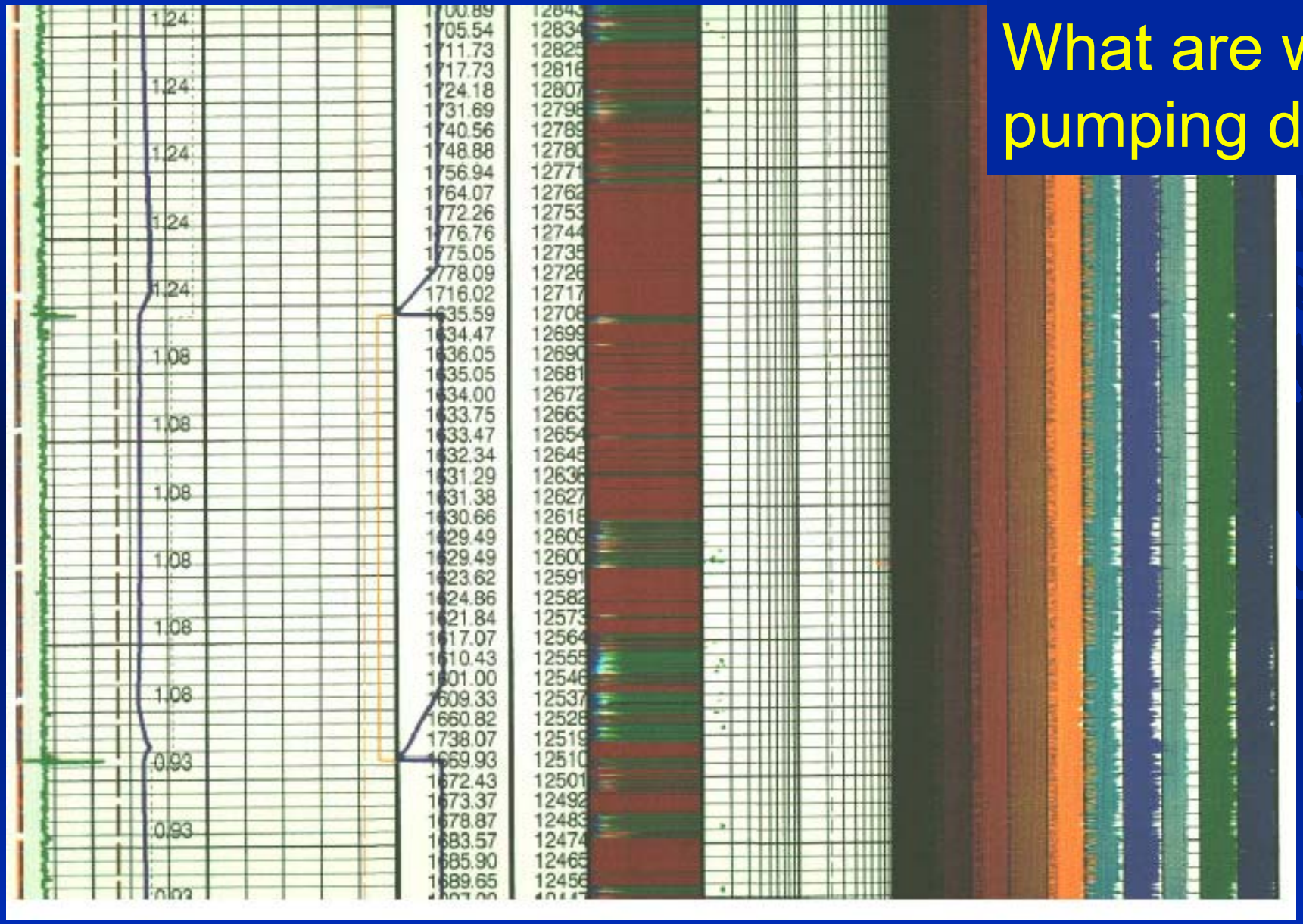
Transient Testing (IPTT): Tests investigating 10's of feet, capturing anisotropy and heterogeneity

In-Situ Stress Testing: Micro-fracturing to get stress magnitude

End of presentation

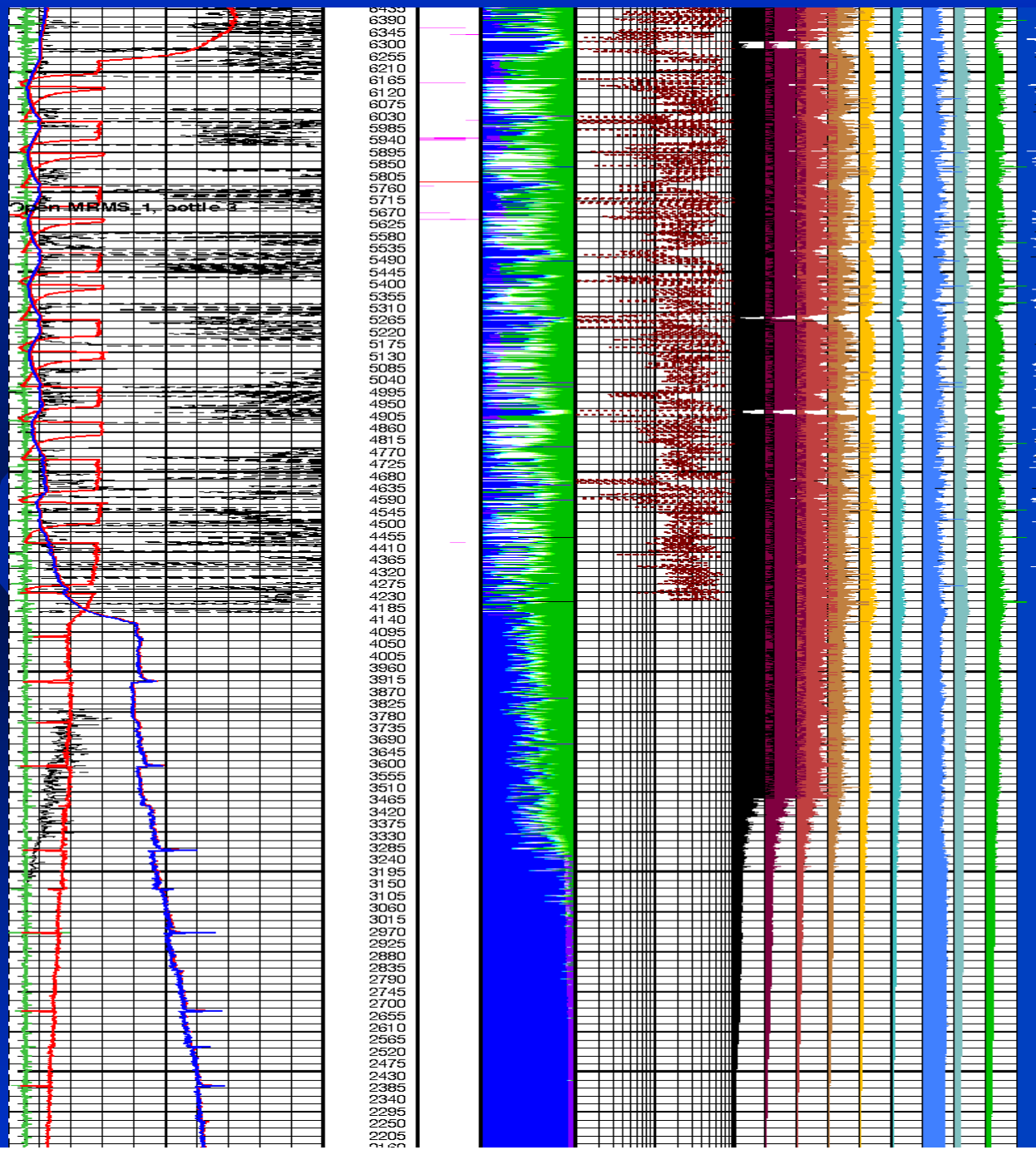
Questions ?

What are we pumping downhole ?



What is happening during this pumpout ?

Water-based mud-trying to sample heavy oil…



What are we pumping ?

Two fluid analyzers are between the pump.