Practical Wellbore Formation Test Interpretation*

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Search and Discovery Article #120009 (2009)
Posted November 20, 2009

*Adapted from presentation at AAPG Geoscience Technology Workshop, "Geological Aspects of Estimating Resources and Reserves," Houston, Texas, September 9-11, 2009

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Abstract

The importance of wireline formation testing (WFT) interpretation increases with the new SEC reserve definitions. This presentation addresses the "reliability" of WFT pressure data to define Proved Reserves in light of the new regulations. We discuss data collection with the different types of tools, explain what constitutes high or low confidence data, and show examples of data trends that might make a compelling case for extending a Proved contact down to a certain point. Other topics will include pretest pressure stability, depth correlation, calculating gradient error, understanding accuracy vs. precision, the importance of mobility, and discuss the difficulty of interpreting WFT gradients in low mobility environments.

Pressure trend analysis is discussed in terms of reservoir compartmentalization, the identification of which early in the life of a high cost development can have significant financial impact to future Appraisal and Development decisions. For compartmentalization studies, it is also important to understand how pressure trends correlate laterally over the field, how pressure trends correlate vertically within each zone, how measured fluid gradients compare to sampled fluid density, how composition, PVT and bulk fluid properties correlate across a field and how each of these trends compare to geochemical marker results. We propose that the integrated analysis of all of these data trends within the geologic model can be used to build a much more compelling case than pressure gradient analysis used in isolation. A list of important references is included.

Practical Wellbore Formation Test Interpretation

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Gulf of Mexico Appraisal Team

Wellbore Formation Testing Outline

- SEC Reserve Definitions
- General description of tools and techniques
  - How good is your data?
- What we are looking for – the Elevator View
  - Examples of good and bad data
  - How to improve confidence in gradients
  - Pretesting in low mobility environments
  - Depth Control and other Issues
- How to avoid compartments
  - The Importance of Integrated View
- Recommendations

SEC Reserve Definitions

Proved reserves: "New Technology = Reliable Technology"

"Reliable Technology is a grouping of one or more technologies (including computational methods) that has been field tested and has been demonstrated to provide reasonably certain results with consistency and repeatability in the formation being evaluated or in an analogous formation."

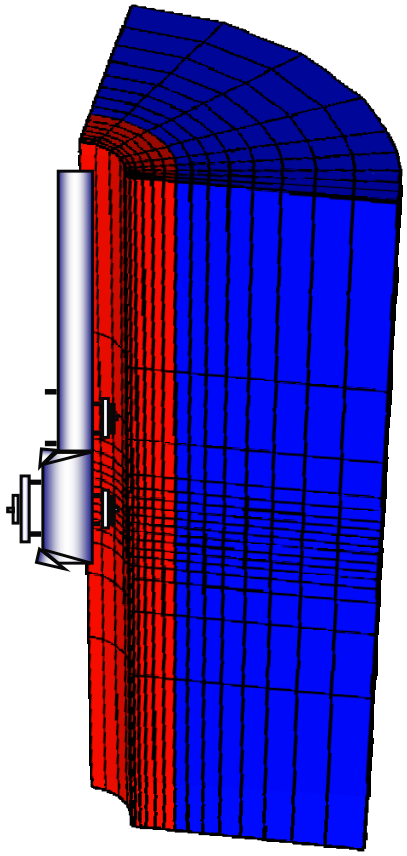
a) Data are of sufficient quality and quantity to be **statistically valid** and **pressure trends indicate continuity** between zones and/or wells

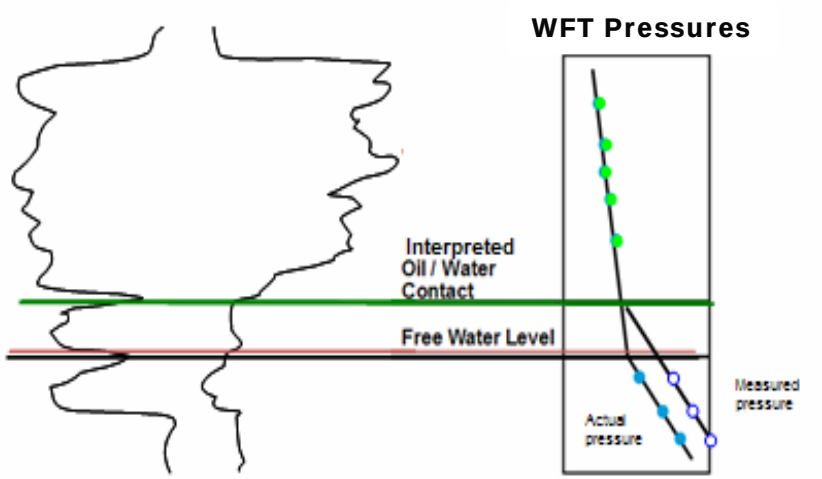
b) **Secondary data** such as the petrophysical model, fluid samples and geochemistry must agree with the geologic model to **indicate reservoir continuity** between zones and/or wells

c) Interpretation of pressure defined GOC and OWC have been shown to have a **high degree of confidence** in analogous formations

An Overview of Formation Testing

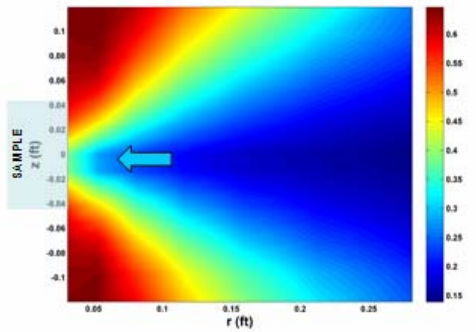
- Many types of Formation Testers run since the 1950's
  - Strain gauges used, limited pressures and poor quality fluid samples
  - Risk of sticking tool was perceived to be high for many years
- Modern tools use highly accurate quartz gauges
  - 100's of pretests possible with a dozen or more fluid samples per run
  - Downhole Fluid Analysis allows high quality samples to be captured
  - Tool sticking risk has been significantly reduced
  - Many different tool configurations possible for different applications
- Pressures while drilling are getting as good as wireline
  - Sampling while drilling tools have been announced





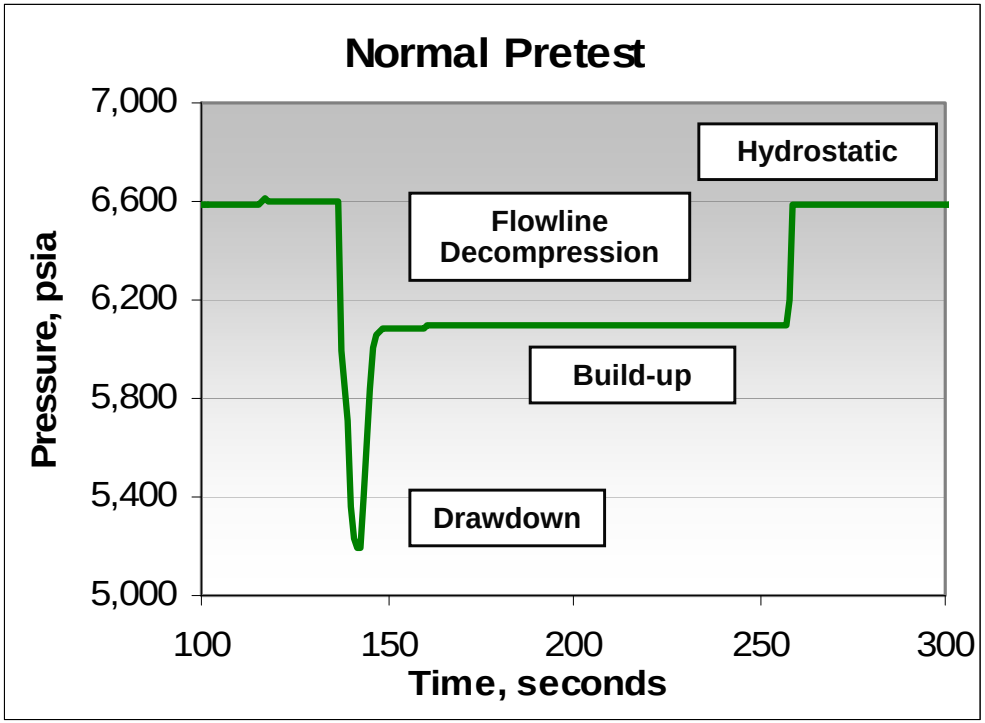
Water-wet rock with OBM capillary pressure effects

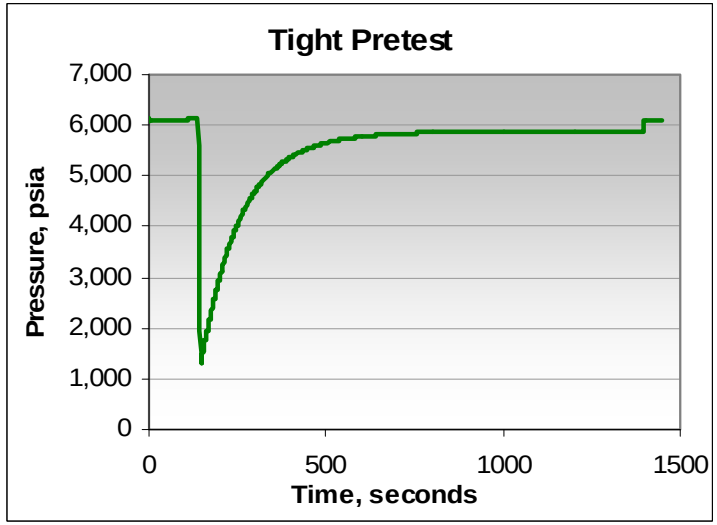
Invaded Zone Formation Fluid

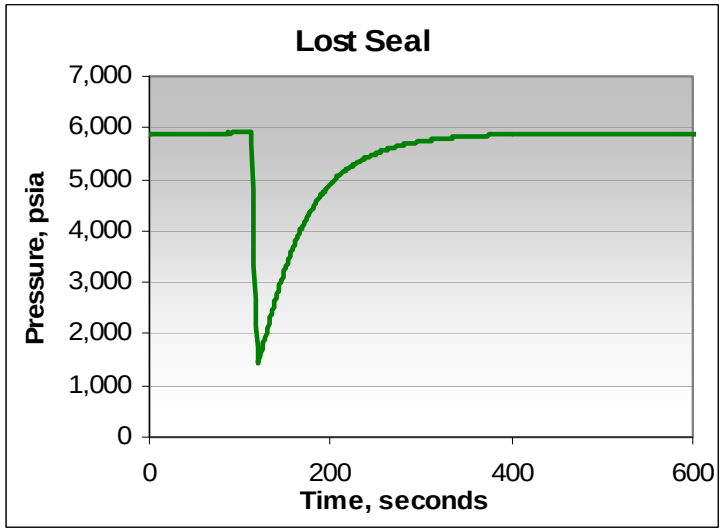


Conventional Probe

Pressures from Pretesting







Normal Test : Pressure builds to formation pressure and is stable

Dry Test: Large drawdown and slow build up

Lost Seal: Packer seal fails – pressure builds to hydrostatic

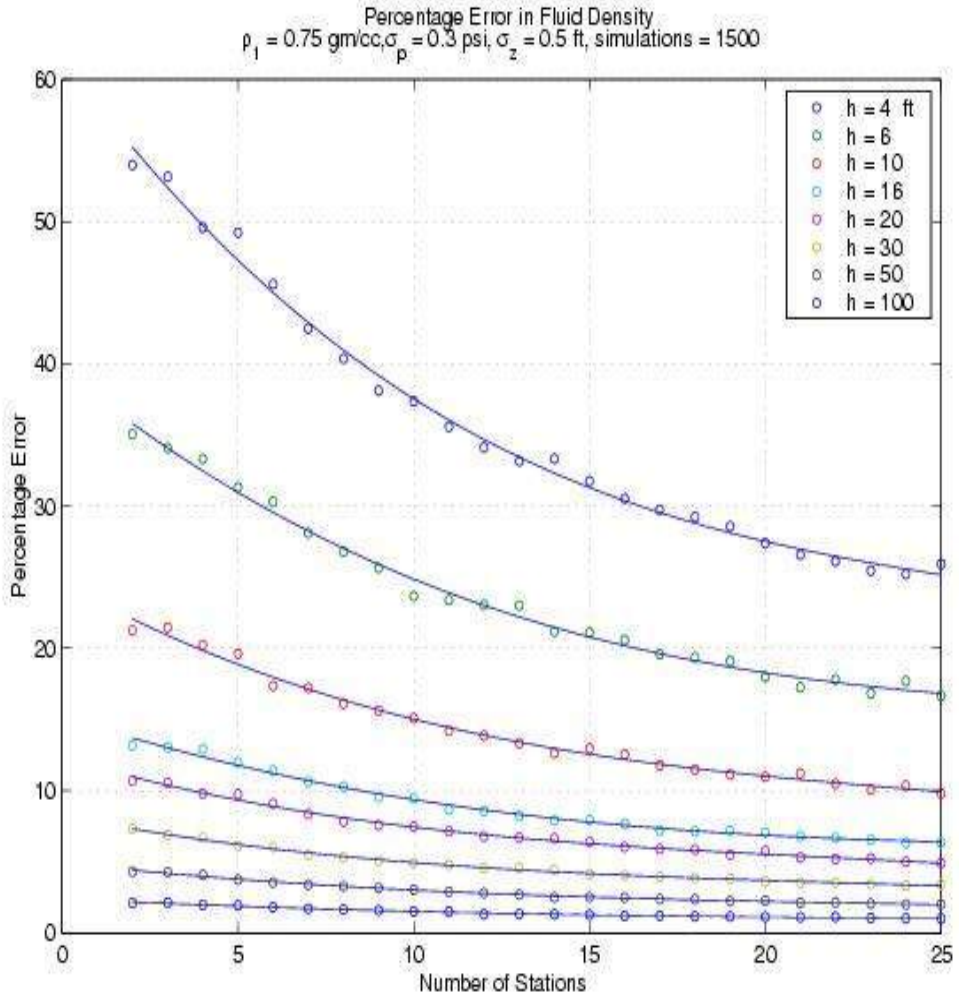
Better idea – Dual Pretests to relieve supercharging, clean up the point and for confirmation of pressure

What We are Looking For – The Elevator View

- “Simplicity is Elegance and Elegance is Power” (in mathematics)
- Auditors are looking for obvious answers to reach a high level of certainty
- Give Auditors what they need in a few pages but have the backup material handy.
  - Demonstrate oil and water gradients with high confidence
  - Demonstrate noise in the data clearly
- A common problem is over-interpreting the data
  - Real data is messy - high-grade data with mobility, excess pressure and other quality control techniques
  - Understand the limits of the analysis
- Don’t interpret pressure gradients in isolation of other data
  - Pressure analysis doesn’t prove a positive, so you need to build a line of evidence supporting your analysis

Gradient Accuracy – Oil

How many points do you need?

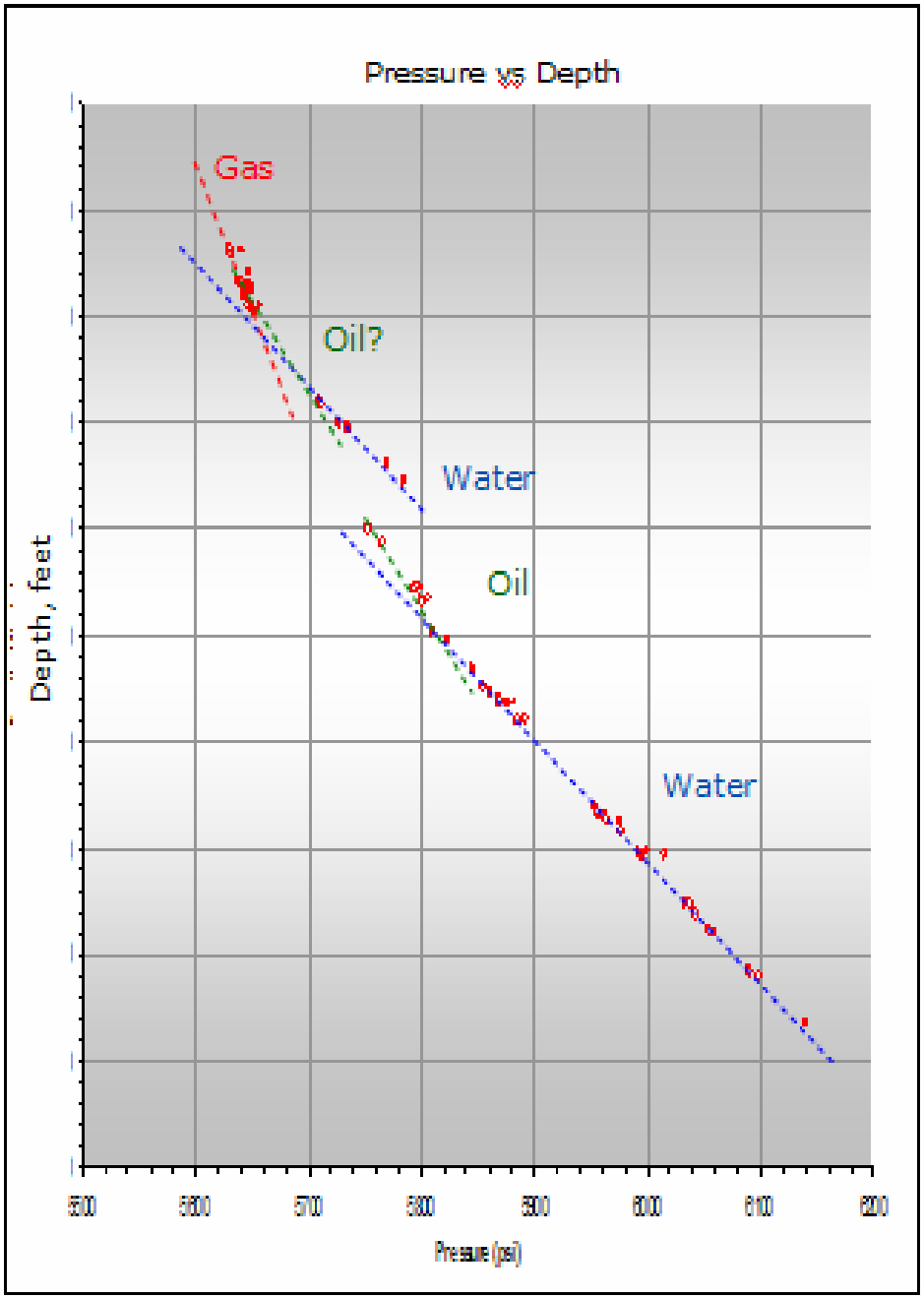


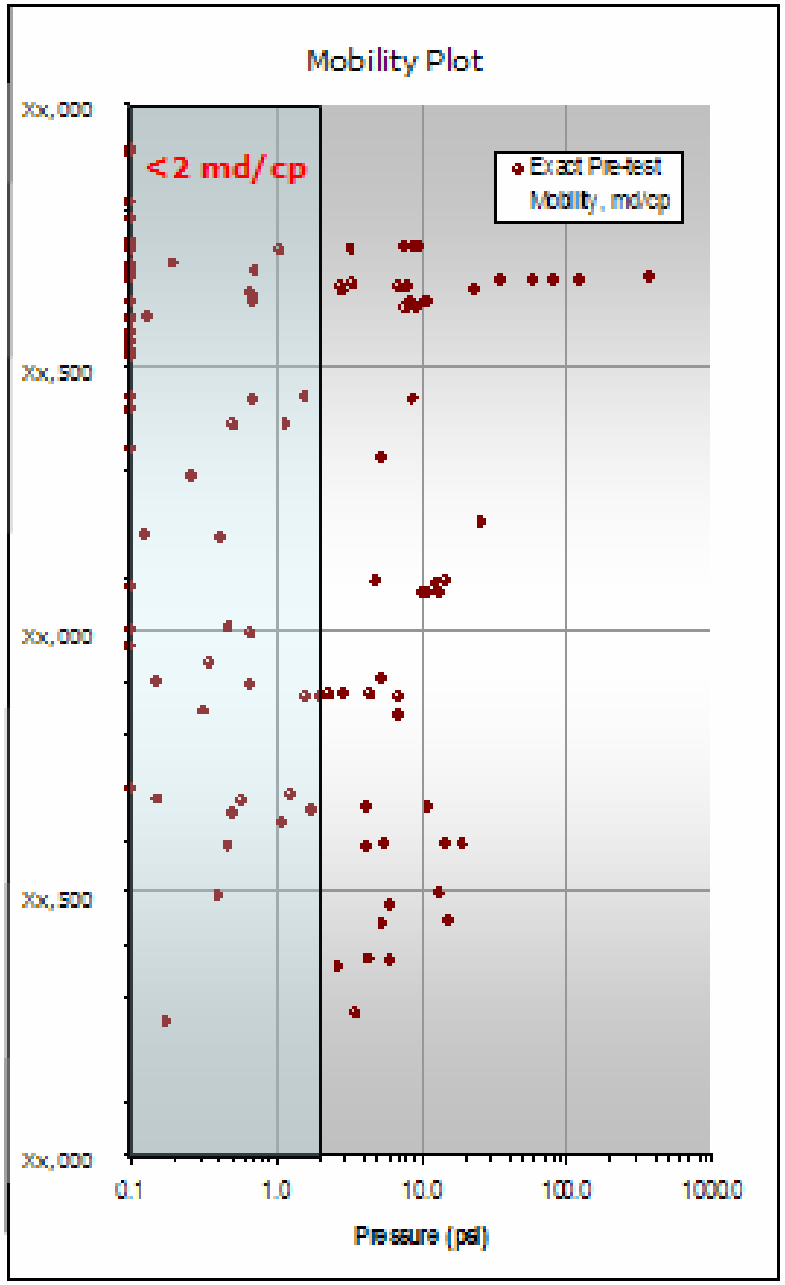
Source J. Pop: SLB Training manual on MDT Interpretation

- While three points does make a very low confidence straight line, no one but a Driller will believe them!
- But no one wants to waste money - remember that gradients don't prove a positive, so what you are really looking for is compartmentalization.
- A VERY general rule is to take pressure points every 10 feet in each sand member.
- In very thick, high kv/kh sands, taking points at top and bottom of lobes can minimize the number of points needed.
- Transition zones require more data and trends can be altered by capillary effects
- In zones less than 20 feet, it is very difficult to get high confidence data.

High-grading Pressure Gradients

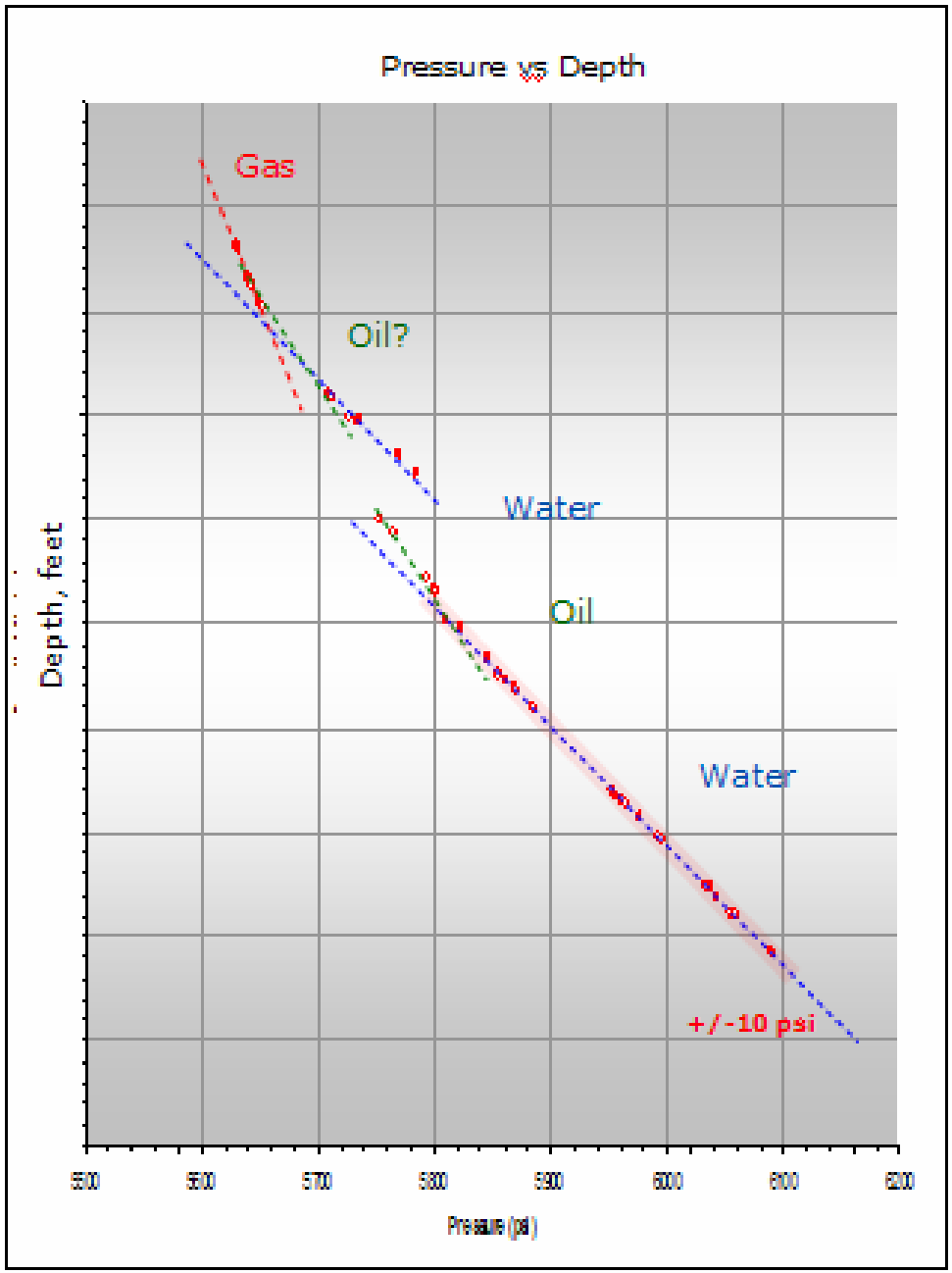
Data scatter can be directly proportional to mobility

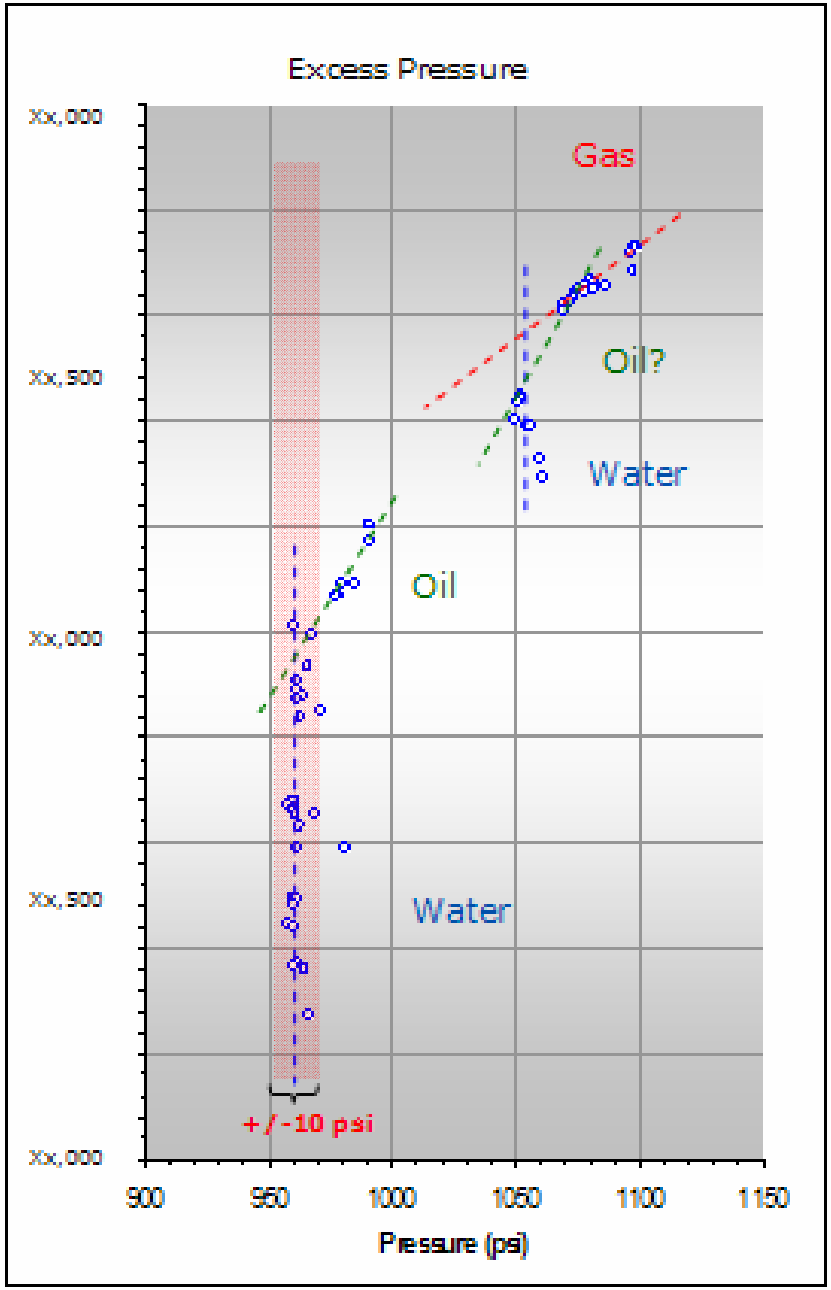




High-grading Pressure Gradients

Excess Pressure is a handy graphical technique





Accuracy and Depth Error in a Well

WFT is not a continuous log run

Deep Water GOM – highly deviated hole

- Several wireline pulls experienced
- Wireline points acquired in two runs
- Points not acquired in sequence of top to bottom due to pulls and many lost seals

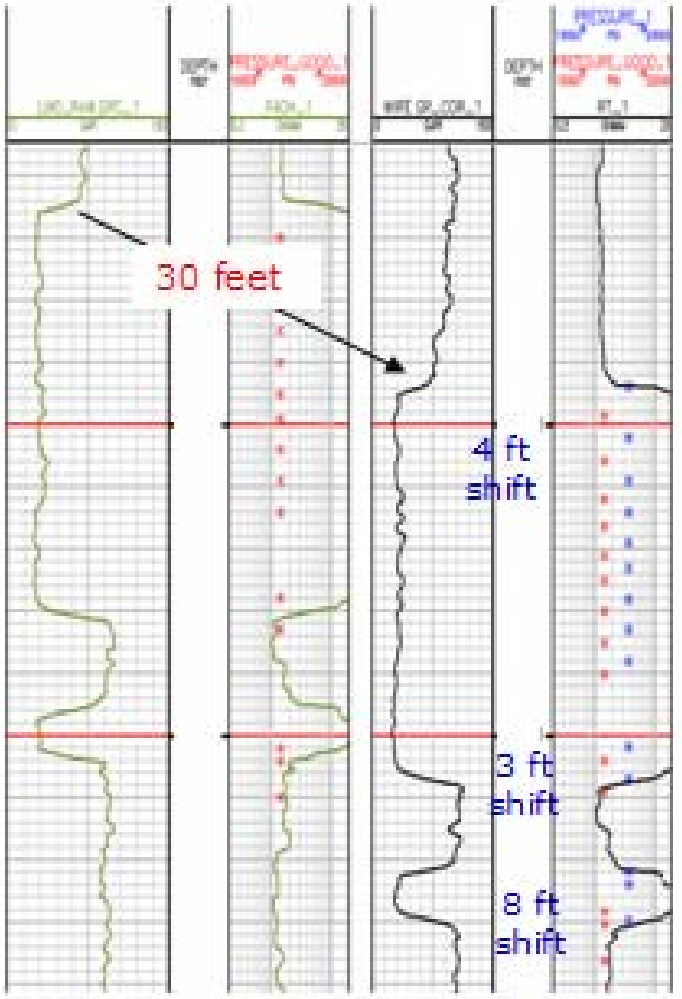
• WFT correlated to LWD: Depth shift between wireline and LWD is 30 feet

• Depth shift of pressure points is not uniform from top to bottom of sand

Remember – WFTs are not continuous logs

Tool movement occurs between every single point

Correlate well and correlate often in difficult holes

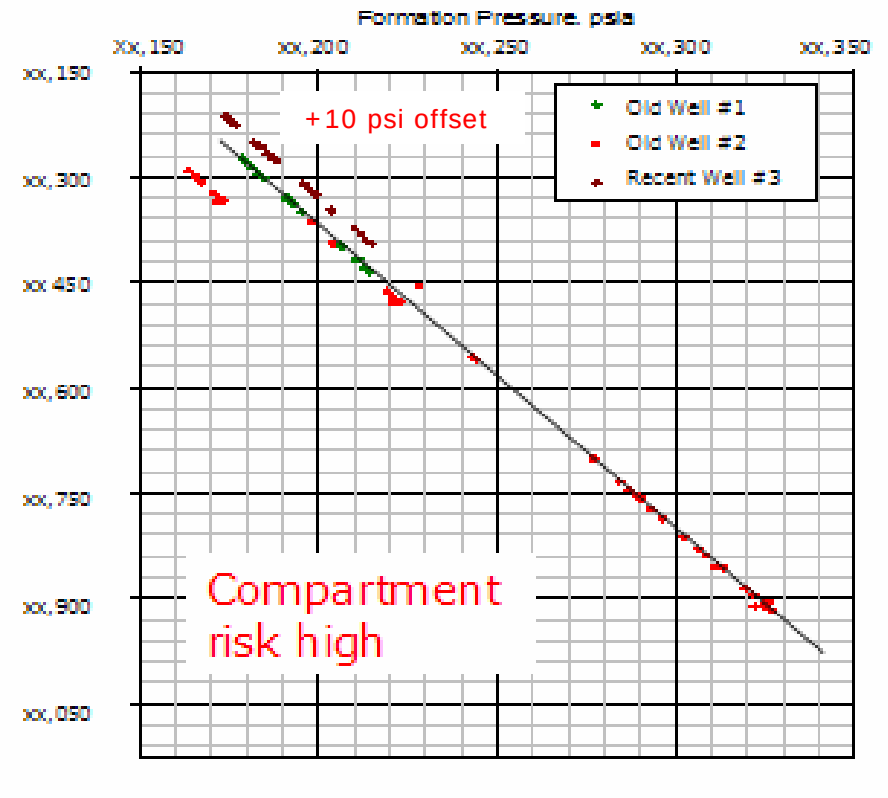


Courtesy Clarke Bean, Chevron

Accuracy and Depth Error between Wells

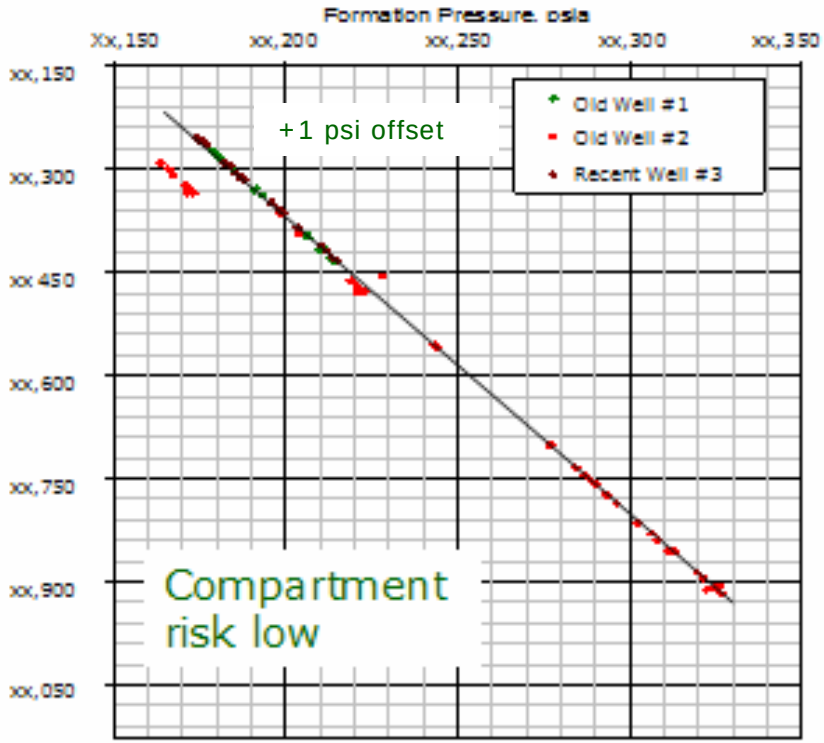
Using downlogs as depth control – a best practice

DWGOM – 24,000' TVD

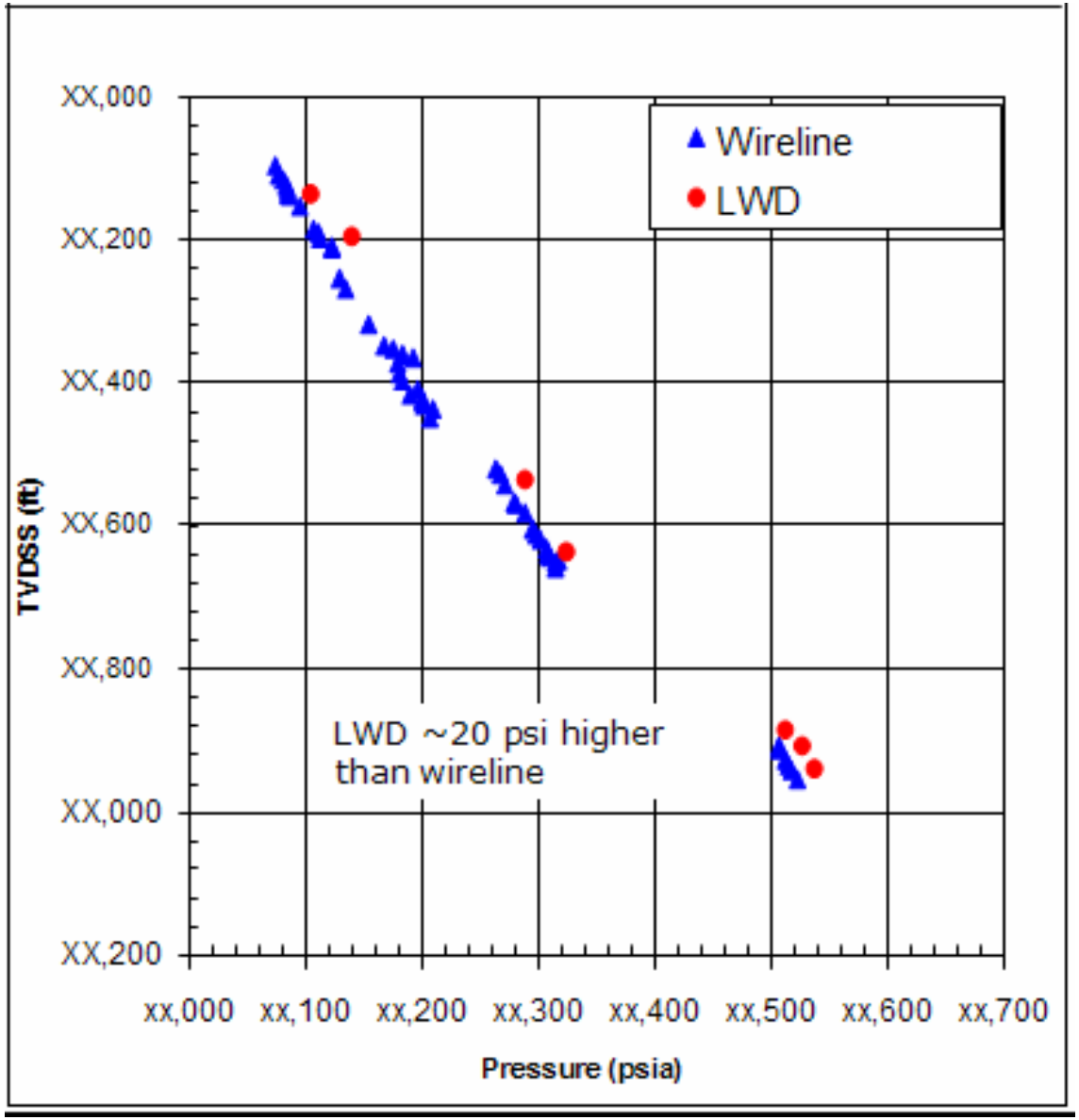


- Wells 1 & 2 correlated to LWD
- Well #3 correlated to wireline, but downlogs run and tied into LWD
- Proper post-job depth control shifts Well #3 down by 42 feet

- Wells 1 & 2 drilled in 2002
- Well #3 drilled in 2008
- Different operator and different rig but same service company



Pretesting in Low Mobility Environments
Common for LWD and Wireline to read differently



Several reasons why LWD and wireline may not agree

- Gauge error or drift
- Depth errors
- Gauge calibration
- LWD during mud cake build
  (dynamic situation of continuing fluid loss)
- Supercharging near wellbore
  (may or may not dissipate by the time wireline is run)
- Logging company errors

Data Observations

- LWD has more noise
- LWD gradients are difficult
- LWD must target thicker, better quality sands.

Pipe Measurements are Exact – Right?

Source of Driller's Depth Errors

- Drill pipe mechanical stretch
- Drill pipe thermal expansion

} 2 largest effects

- Variable friction factors (sliding/rotating)
- Rig heave
- Tidal errors

} Next order of magnitude

- Buoyancy force
- Unsynchronized clocks

Keep it within seconds

- Pressure effects
- Pipe strapping errors
- Setting slips effect

} No correction exists

- Documentation to fix errors is rarely archived…

Accuracy and Depth Error between Wells
How much error can we expect?

1	Calibration difference between probes:	1 psi	+/-	(Could be greater if equipment is poorly maintained)
2	Accuracy of pressure elements	4.5 psi	+/-	(Published by Vendor 2.0 psi + 0.01% of reading))
3a	Accuracy of depth control in oil sand	18.7 psi	+/-	
3b	Accuracy of depth control in water sand	23.3 psi	+/-	
	Oil Gradient	0.365 psi/ft	+/-	
	Water Gradient	0.455 psi/ft	+/-	
	Baker Hughes Inteq calculated vertical error	48.8 feet	Well 1	
	Survey Vendor Error of Ellipse Calculation	52.1 feet	Well 2	25,000' TVD well
		47.4 feet	Well 3	
		56.1 feet	Well 4	
		51.1 feet		
4a	Resulting range of error in oil sand	24.2 psi	+/-	
4b	Resulting range of error in water sand	28.8 psi	+/-	

- Within a wellbore in a single run, quartz pressure gauges are very accurate
  - Expect pressure trends to be within 1-2 psi with good quality control
- Plotting data from runs on different wells can be problematic due to depth issues.
- A VERY general rule of thumb might be to expect pressure trends to be off as much as +/-10 psi for every 10,000' TVD, if modern depth control techniques have not been used.
- Two recent major field studies in DWGOM recommended shifts of 45 to 75' TVD for several wells where downlogs were available for wells drilled over several years.

How to Avoid Compartments

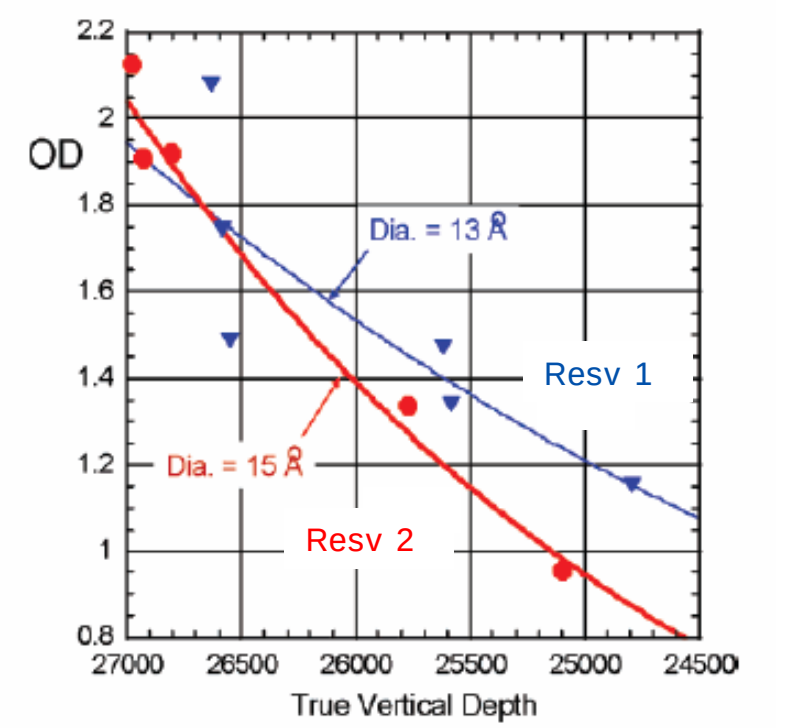
Compartment Risk based on how:

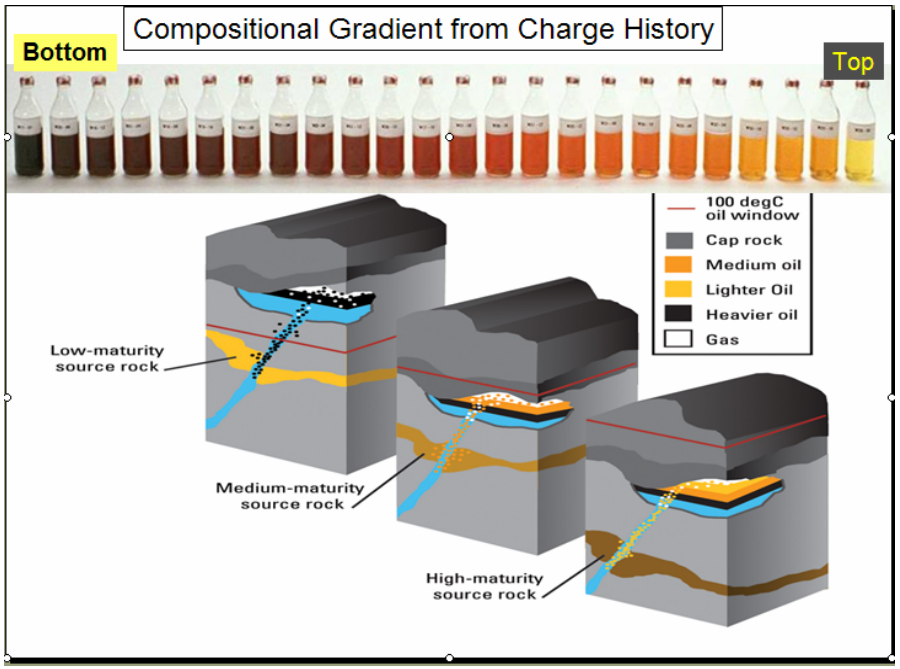
- Pressure trends correlate laterally over the field,
- Pressure trends correlate vertically within each zone,
- Measured and theoretical fluid gradients compare,
  - EOS models are cheap to build!
- Composition, PVT and bulk fluid properties correlate within each zone, and
- A review of geochemical marker results including:
  - Oil Fingerprinting & Source Rock Analysis
  - Sulfur Isotope Analysis
  - Solution Gas Isotope Analysis
  - Mud gas Isotope Analysis from Mud Log shows

Many oil companies now "assume that a reservoir is compositionally graded until proven otherwise". In long columns modeling and successfully measuring a slight gradient can help prove vertical continuity.

How to Avoid Compartments
Fluid Sampling can be key

- We need **multiple fluid samples from different wells** because spatial variations in fluid composition can reflect:
  - Faulting, compartmentalization and reservoir architecture
  - Filling history as an indication of geologic complexity
  - Proximity to fluid contacts and gravitational grading
  - Biodegradation, tar mats, loss of light ends and mixing events
  - and allow production allocation or mechanical troubleshooting with fingerprints
- Downhole fluid analysis can identify some of these parameters **while sampling**!
  - This is useful both between sample points in a well and between wells.



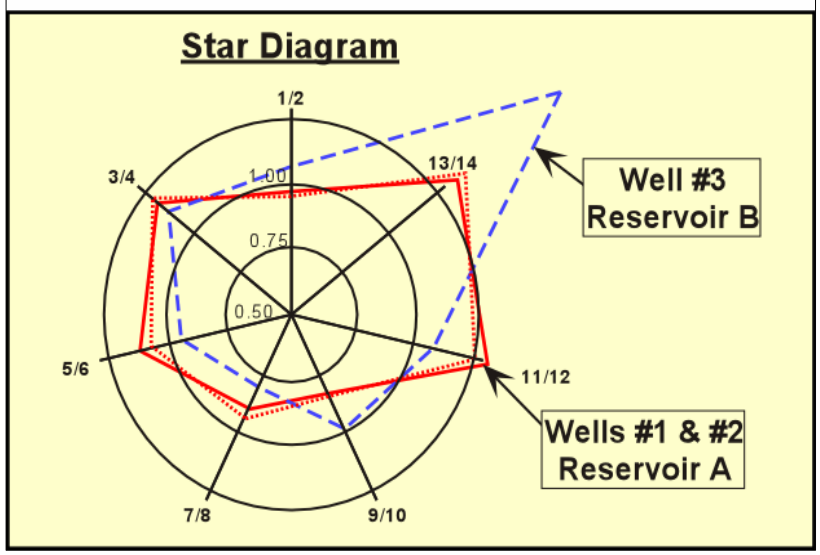


Courtesy Oliver Mullins, Schlumberger

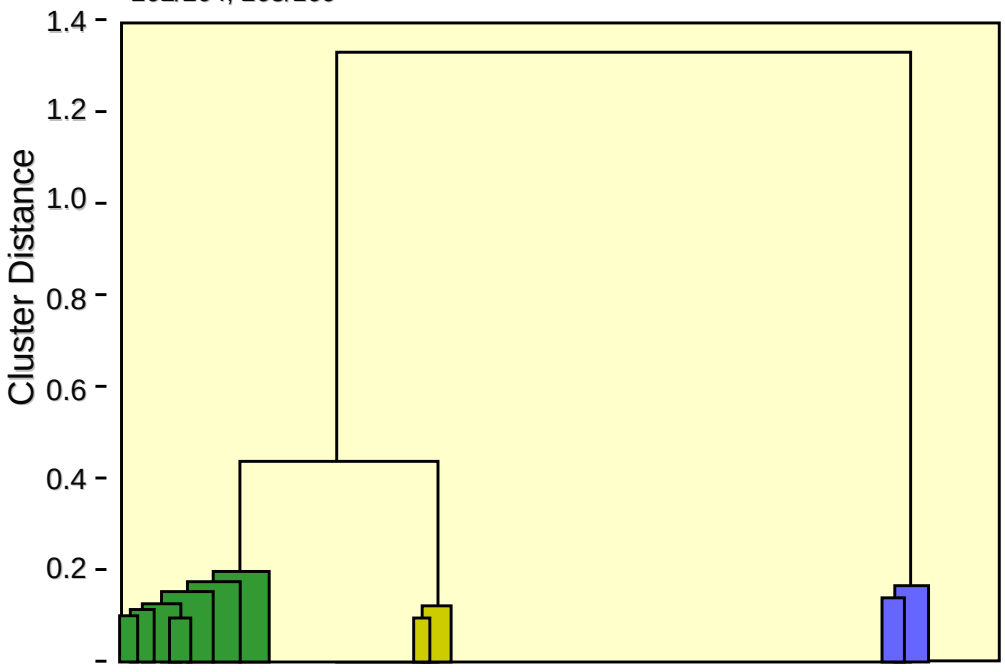
Once you have the Sample, Geochemistry is Cheap
Fingerprints Plotted Using a Star Diagram and Dendrogram

Hydrocarbon Peak Ratio Table

Well	1/2 Ratio	3/4 Ratio	5/6 Ratio	7/8 Ratio	9/10 Ratio	11/12 Ratio	13/14 Ratio
#1	0.90	1.17	1.12	0.85	0.82	1.26	1.26
#2	0.86	1.19	1.09	0.87	0.82	1.25	1.29
#3	1.04	1.10	0.90	0.79	0.98	1.05	1.71



Ratios: 77/74, 122/119, 84/86, 67/63, 245/250, 143/148, 132/137, 110/106, 145/149, 103/108, 191/195, 125/124, 129/127, 85/87, 76/75, 172/175, 116/121, 242/240, 64/68, 108/113, 38/42, 138/141, 199/201, 202/204, 263/169



- Oils in fluid communication in a reservoir have nearly identical fingerprints and star diagrams.
- Oils in separate reservoirs have different fingerprints and star diagrams.
- Cluster analysis is a multivariate statistical technique for grouping samples based on their similarity to one another. The dendrogram is defined from peak height ratios.
- The near real-time application of these methods during fast-paced Exploration and Appraisal is a very intensive process, but is well worth the effort!

Courtesy Stan Teerman and Russ Kaufman, Chevron

Running WFT Tools can get Ugly!

Data isn't free – carefully consider VOI

Knotty Head Prospect:
Deepest Oil and Gas Well
in the World at 34,189' MD
(at the time)

World record depth for
fishing formation tester
and 30,000' of wireline!
(Samples successfully retrieved to surface after two weeks)

Transocean Deepwater Spirit

Wellbore Formation Testing Best Practices

1) Create simple, straight-forward presentations showing OWC interpretations in which the use of good Engineering judgment is obvious

- Provide backup data in an Appendix

2) Consider all secondary data available and show very clearly how this data supports a connected reservoir interpretation

- Regional Pressure trends, Fluid Properties, Geochemical trends

3) Acquire high quality fluid samples if practical

- In general, OBM contamination is directly proportional to pumpout volume. Use real-time optical analyzers to optimize rig time and sample quality. Make sure you capture a set of relevant drilling fluid samples.

4) When planning WFT runs, create flexible plans that ensure data quality and quantity guidelines can be met

- Assign an experienced Wellsite Geologist to the job and provide remote QA/QC if possible. Remember all critical logging decisions are made at 2AM.
- Acquire pressures in as uniform a manner as possible
- Quartz gauge pressures are very accurate, depth control isn't
- Immediately after the job, QA/QC the data and properly archive the run.
- Poor quality data can be worse than no data at all; if you are going to invest the capital on a WFT run, spend the time to do it right!

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