RYDER SCOTT 2010 Reserves Conference

The Demonstration of a Reliable Technology for Estimating of Oil and Gas Reserves

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Disclaimer

The opinions expressed herein are those of the author alone. These opinions have not been reviewed with or approved any organization or agency that may be mentioned in this presentation.

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Background and Reference

At the 2009 Ryder Scott Reserves Conference, John Hodgins provided key information on Reliable Technology ("R.T."):

- SEC regulations where R.T. is mentioned
- Colloquial definitions for "reliable" and the key standards of "consistency" and "repeatability"
- Need for good documentation to support the claim of a reliable technology including sufficient case histories and empirical data to provide irrefutable evidence of reliability

(Presentation available from Ryder Scott website)

Background and Reference

John also posed this question about some technologies that could potentially be R.T.

"For example, can I use…."

- **Fluid Gradient vs. Depth Data**
  - Fluid contacts
  - Vertical or horizontal continuity
- **Seismic**
  - Fluid Contacts
  - Reservoir Continuity
  - Net pay, porosity or fluid saturation predictions and lateral distributions (i.e., away from well control)
- **Reservoir Simulation**
  - Without a history match

Background and Reference

Two of these examples are addressed in this presentation:

- **Fluid Gradient vs. Depth Data**
  - ✓ **Fluid contacts**
  - • Vertical or horizontal continuity
- **Seismic**
  - ✓ **Fluid Contacts**
  - • Reservoir Continuity
  - • Net pay, porosity or fluid saturation predictions and lateral distributions (i.e., away from well control)
- **Reservoir Simulation**
  - • Without a history match

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Other References

- SPE 129689 – The Demonstration of a "Reliable Technology" for Estimating Oil and Gas Reserves
  - Given at SPE HEES (Dallas) March 2010
- SPE 134237 – Qualifying Seismic as a "Reliable Technology" – An Example of Downdip Water Contact Location
  - To be given at SPE ATCE (Florence) September 2010
- Co-authors of both papers are Rod Sidle and Dr. John Lee

R.T. – Good background, now what?

- We need a methodology for demonstrating reliability that will satisfy both a technical standard as well as a regulatory (i.e., legal) standard for valid, convincing evidence.
- Consider the rules used by the Federal Courts for scientific testimony. These have been established to guide courts when "expert" scientific testimony is used in legal proceedings.

Rule 702

- Rule 702 of the US Federal Rules of Evidence which instructs scientific testimony be based on <u>sufficient facts or data</u>, and the <u>product of reliable principles and methods</u>
- Later the US Supreme Court clarified this: The reliability standard established by Rule 702 requires <u>scientific knowledge which implies a grounding in science's methods and procedures</u>

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“Science’s method and procedures”

- How does the field of science define this?

“Reliable knowledge is knowledge that has a high probability of being true because its veracity has been justified by a reliable method...The method used to justify scientific knowledge, and thus make it reliable, is called the scientific method.”

-- Professor Steven D. Schafersman, 1997

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Scientific Method: Steps

1. Define the question
2. Research the question and formulate a hypothesis (define the theoretical science behind your R.T.)
3. Perform experiments; collect and analyze the data (test your R.T.)
4. Interpret data; draw conclusions; document results
5. If necessary, revise hypothesis and repeat steps 3 and 4

Scientific Method: Adapted to Demonstrating a R.T.

1. Define how the R.T. will contribute to reserve estimation (e.g., define OWC)
2. Research the science behind this application; define when results are valid
   a) How should the R.T. work in perfect (ideal) situations
   b) What are the assumptions behind the successful use of the R.T.
   c) What real-life (non-ideal) conditions will impact the application of the R.T.

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Scientific Method: Adapted to Demonstrating a R.T.

3. Test to validate the hypothesis and demonstrate requirements for R.T. have been met.
   a) Can be both new tests and hindcasting
   b) Make a statistically significant number of tests
   c) Should confirm limits on successful use by testing expected failure situations (to know what failure looks like)
4. Document results including conditions needed to achieve reliability (i.e., what are the limits on successful application)

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Scientific Method for R.T. – Some further thoughts

- Include all test data in documentation; selective exclusion of data will cause questions about consistency and repeatability
- Keep the analysis/documentation updated with new data as the R.T. is used. Does this change your conclusions on limits, application?

Apply this to Fluid Pressures (or Gradients) vs. Depth cross-plot

- Good example is found in “Estimation and Classification of Reserves of Crude Oil, Natural Gas, and Condensate” by Chapman Cronquist (see Appendix G)
- This describes the use of such cross-plots to estimate fluid contact location in hydrocarbon reservoirs
- Let us now fit this into the steps of the scientific method...

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Cross-plot example: Step 1

- The question is "can data relating depth and the fluid pressures of two continuous phases be used to calculate the elevation of the contact of those fluids...?"
- This may be further modified to be specific to the location and formations where the hypothesis is to be tested. Thus for this example we add "…for Pliocene-Miocene turbidite sand reservoirs in the Gulf of Mexico".

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Cross-plot example: Step 2a

The science behind this method is:

- At the fluid contact depth, pressure in each phase will be equal.
- At any given depth, x, the fluid pressure of one phase, f, can be related to the pressure at a measured depth, m, and the gradient of the fluid, G_f. Thus,

$$p_{f|x} = p_{f|m} - G_f (m - x)$$

- Gradient can be found by either fluid sample or multiple measurements of pressure-depth.

Cross-plot example: Step 2b

Assumptions (that must be confirmed):

- Both hydrocarbon fluid and water samples are from a single, continuous reservoir
- Samples of oil and water are representative of that phase throughout the reservoir (no variations in composition, thus density)
- Measurements are accurate and sufficiently precise for extrapolation beyond depths where taken
- All available data give a consistent result for the contact location

Cross-plot example: Step 2c

What could go wrong?

- Typically invalid assumptions masked by difficult situations, such as:
  - Measurements in different reservoirs due to limited continuity (low net/gross sand?) or log mis-correlations
  - Inaccurate pressure data due to poor well bore conditions
- Learn from testing what are the key risk factors in use of the technology and incorporate checks in your process

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Cross-plot example: Steps 3 & 4

- Collect the data
  - Need statistically significant number of tests
- Analyze hypothesis
- Confirm situations where reliability is demonstrated
  - Testing should include a failure case to ensure you know what failure looks like
- Document results
- Update as method is applied and new results are captured

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Applied to Reserve Estimation

Consider how these results will be applied:

- If for proved, do the results clearly support "reasonable certainty" in the reserves based on this R.T.?
  - The estimation of 20 PUDs based on a R.T. may be convincing with 100 cases to support the technology but may not be convincing if only 5 cases support it.
  - Consider the number and quality of your test cases when deciding the amount of additional reserves your R.T. can justify

Extending this to complex technologies

- Which do you trust most:

Determination of fluid contact location by...

Observe directly with well log through contact	Calculate from proximal wells and measured pressures	Estimate from remote measuring (seismic) and complex analysis

All can give correct answers; Some require much more effort and analysis to give high confidence in those answers.

Seismic for Fluid Contacts

- Let's take a quick look at qualifying seismic as a R.T. for estimating the location of a hydrocarbon-water contact
- This is covered in more detail in a coming paper, SPE 134237, to be given in Sept 2010 at the SPE ATCE
- As we now understand, this is more challenging than qualifying a pressure gradient cross-plot technique

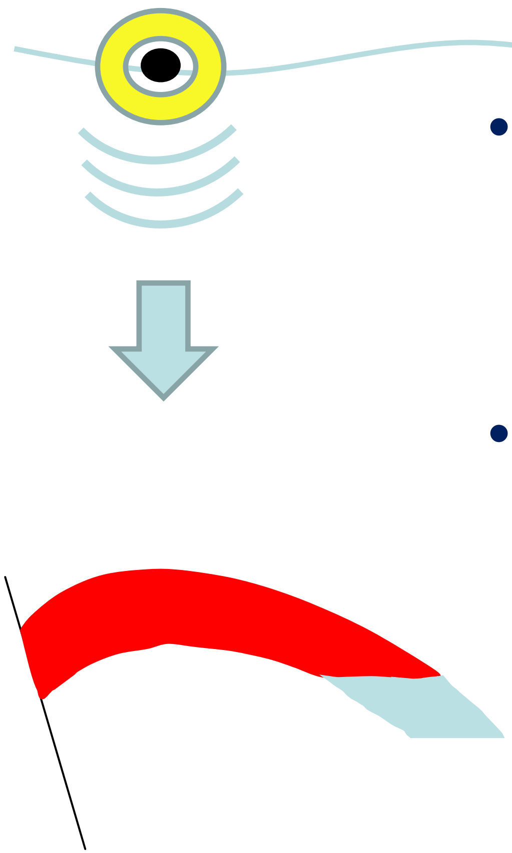
Seismic example: Steps 1 & 2

1. Can seismic reliably identify HC/water contact?
2. The science behind the hypothesis:
   a. In applications where no interfering effects distort high-quality, 3-D seismic data, the portion of the seismic related to fluid content of the reservoir can be isolated and analyzed.
   b. Conclusive interpretation of the fluid contact between a commercial HC reservoir and an aquifer requires the additional condition of distinctly different seismic amplitudes for “pay” v. residual HC saturation or aquifer.

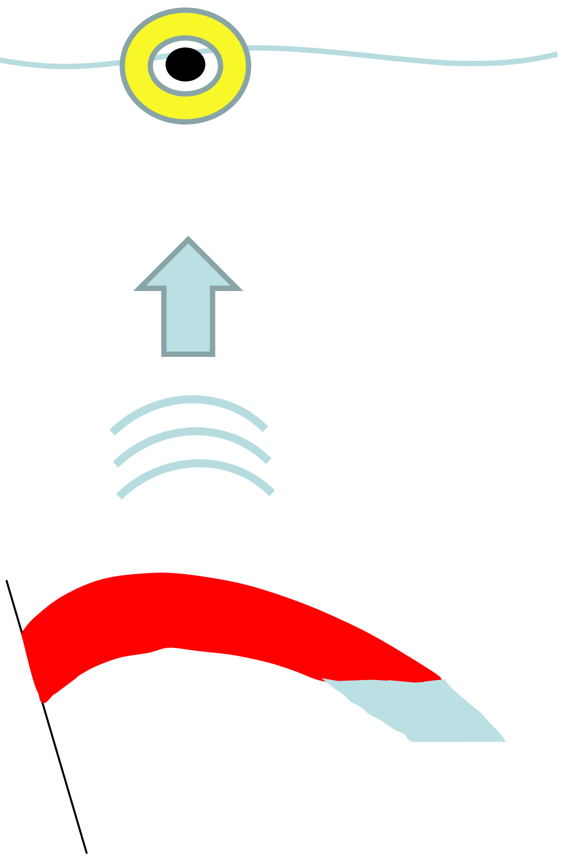
Seismic AVO – Zero Offset

"Amplitude Variation with Offset"

Source / Receiver

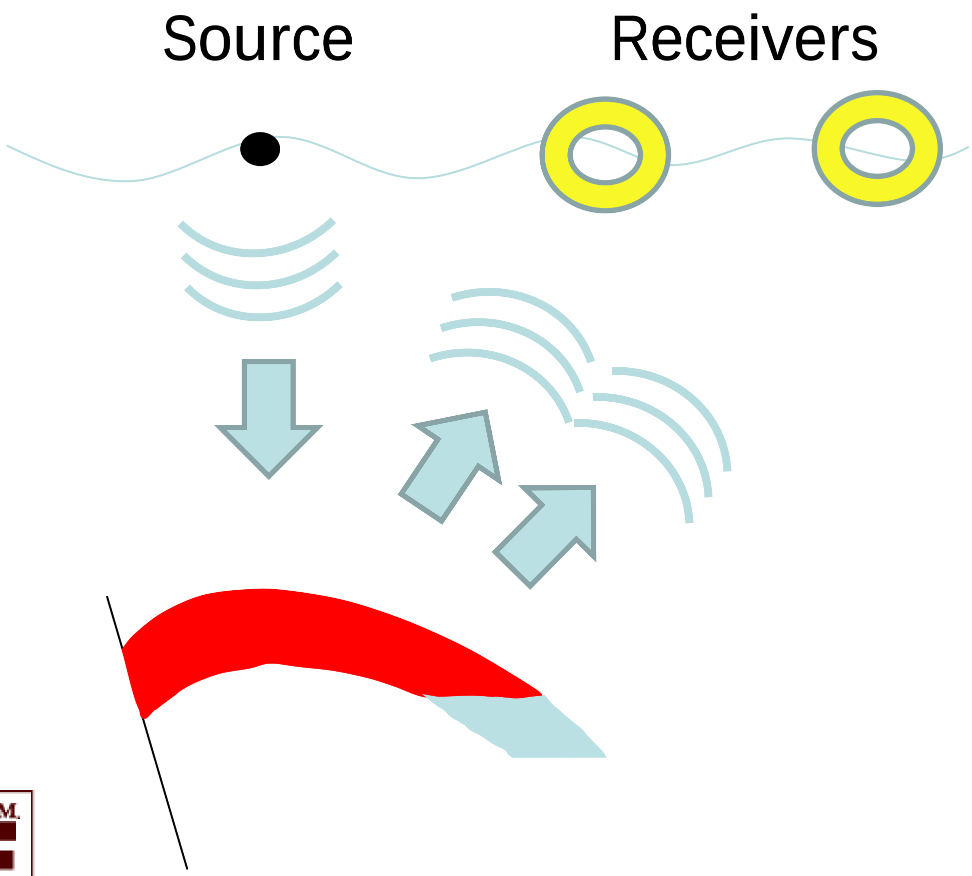


Source / Receiver



- Reflective event directly below source
- Seismic data captures only the "p-waves" which move in the direction of the propagated wave

Seismic AVO – With Offset



- Seismic reflective signals (amplitudes) are converted waves with both a vertical ("p-wave") and lateral ("s-wave") component

- Shear ("s") waves have different characteristics than p-waves allowing additional information to be extracted from the seismic

Ensure applicability – are all conditions right for success?

- Quality control of data – e.g., well logs provide good, complete data which ties to zero-offset seismic
- Stratigraphy – e.g., no stratigraphic variations that would compromise the fluid signal interpretation
- Structural factors – e.g., good “fit to structure” of the apparent contact
- …and others which develop a checklist

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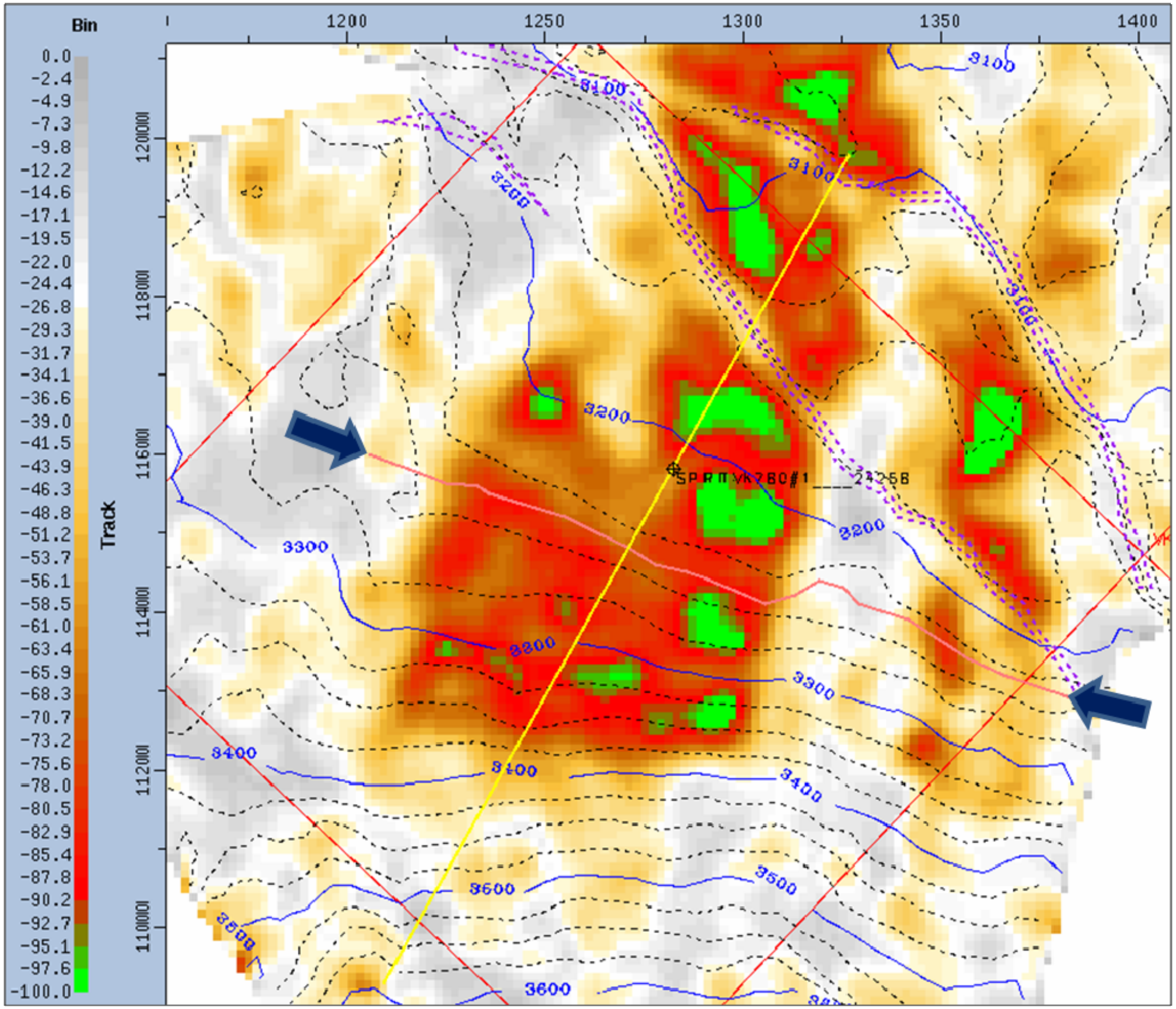
Successful "negative" case



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Seismic example: Summary

- Complex technologies can be shown to provide consistent and repeatable results to achieve reliability.
- Careful consideration of qualifying conditions required for reliability is key.
- This may mean starting with a very narrow window of application (“perfect conditions”) then broadening the scope of successful (reliable) use.

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Extending this to complex technologies

- We discussed this challenge...

Determination of fluid contact location by...

Observe directly with well log through contact	Calculate from proximal wells and measured pressures	Estimate from remote measuring (seismic) and complex analysis

All can give correct answers; Some require much more effort and analysis to give high confidence in those answers.

Extending this to areal/dynamic factors

- Now consider a different dimension - How well can we determine with high confidence:

The value of a reservoir property that is...

Localized (only one location in a reservoir) and static	Spread over a broad area (throughout the reservoir) and static	Spread over a broad area and dynamic (changing with time)
Examples:		
Initial fluid contact depth	Porosity distribution	HC saturation distribution while producing

Revisit R.T. Target List

- Recall the list of R.T. targets:
  - **Fluid Gradient vs. Depth Data**
    - ✓ **Fluid contacts**
    - Vertical or horizontal continuity
  - **Seismic**
    - ✓ **Fluid Contacts**
    - Reservoir Continuity
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Industry's Challenge on R.T.

- **Fluid Gradient vs. Depth Data**
  - ✓ **Fluid contacts**
  - Vertical, horizontal continuity
- **Seismic**
  - ✓ **Fluid Contacts**
  - Reservoir Continuity
  - Net pay, porosity or fluid saturation predictions and lateral distributions
- **Reservoir Simulation**
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- Contacts are localized, static
- Continuity and predicted distributions are broad area, static
- Simulations (for production, recovery) are broad area, dynamic

➤ **Can we meet this challenge?**

Challenge accepted

Yes, I believe we can if we....

- Use and develop technologies based on sound and defensible science
- Demonstrate reliability using accepted methods and thorough testing
- Provide complete documentation (updated as more is learned)
- Share our learning to build a collective industry capability

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How to relate R.T. and analogy?

- Q: The Dec 2009 SEC update of Reg. 4-10 describes the demonstration of a R.T. as "in the formation being evaluated or in an analogous formation". To use a R.T. by analogy, do you first qualify the R.T. and then establish analogy or the reverse?
- A: First demonstrate the R.T. in those formations where the testing/validation has been done. Then establish the analogy with certain of those formations.

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Relating R.T. and analogy

- A (why): The demonstration of the R.T. includes the science behind the technology and empirical data to show when/how it works. This should include defining those key criteria needed for the R.T. to work (and those where it will fail). These key criteria are then used as part of the "effective aggregate" of compared reservoir properties to define when a valid analogy exists.

What is an “analogous formation”?

- A: At the minimum, this is the same as an “analogous reservoir in the same geological formation”. But perhaps more. The analogy proposal must consider and compare the important characteristics of the reservoir, formation and other geologic units that impact the conclusion being drawn to demonstrate the validity of the analogy application.
- Reference: SPE 129688, Appendix A or come to the Houston SPEE Luncheon, Nov. 3, 2010

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