Two talks today:
1) Ultrasonics and fractures
2) Reservoir reserve likelihood

Spindletop, Beaumont – (g)ushered in a new era of advancement

Physical modeling of anisotropic domains: Ultrasonic imaging of laser-etched fractures in glass & 3D print slots

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+ConocoPhillips, Houston

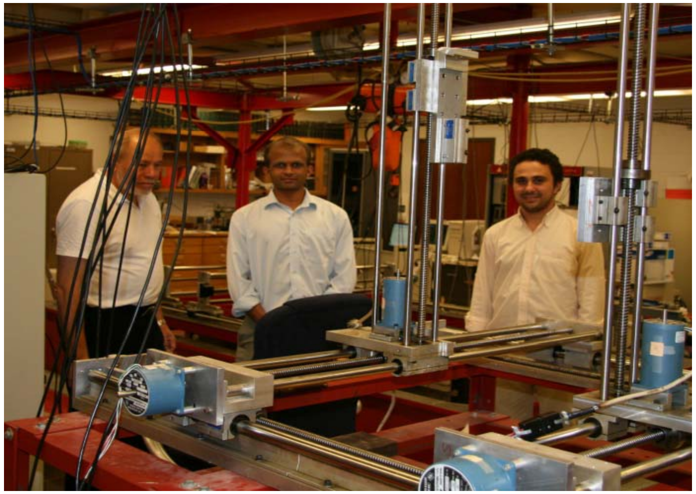
ConocoPhillips

UNICAMP

CREWES Sponsors Meeting Banff Dec. 2nd, 2011

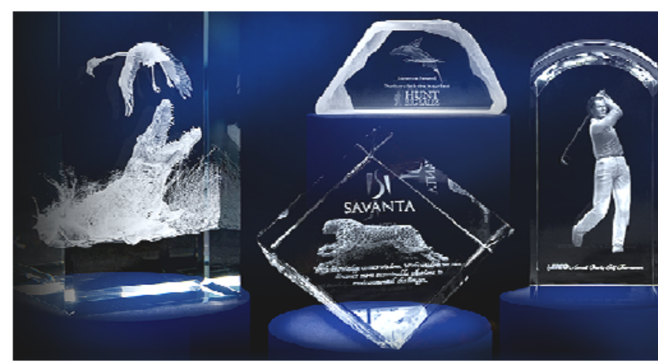
Outline – Ultrasonic imaging of fractures

- Motivation for work
  - Develop resources in natural & induced fracture zones
  - Make a seismic image of fracture zones
  - Complement and extend numerical modeling
  - Find signature related to fracture parameters
- New models & experimental apparatus
  - Epoxy inclusions, laser-etched crystals, 3D printed plastic
  - 3C ultrasonic sources & receivers
- Measurements
  - Transmission, reflection, 3C-3D
- Results
  - What' s observable,
  - Role of wavelengths, Directions

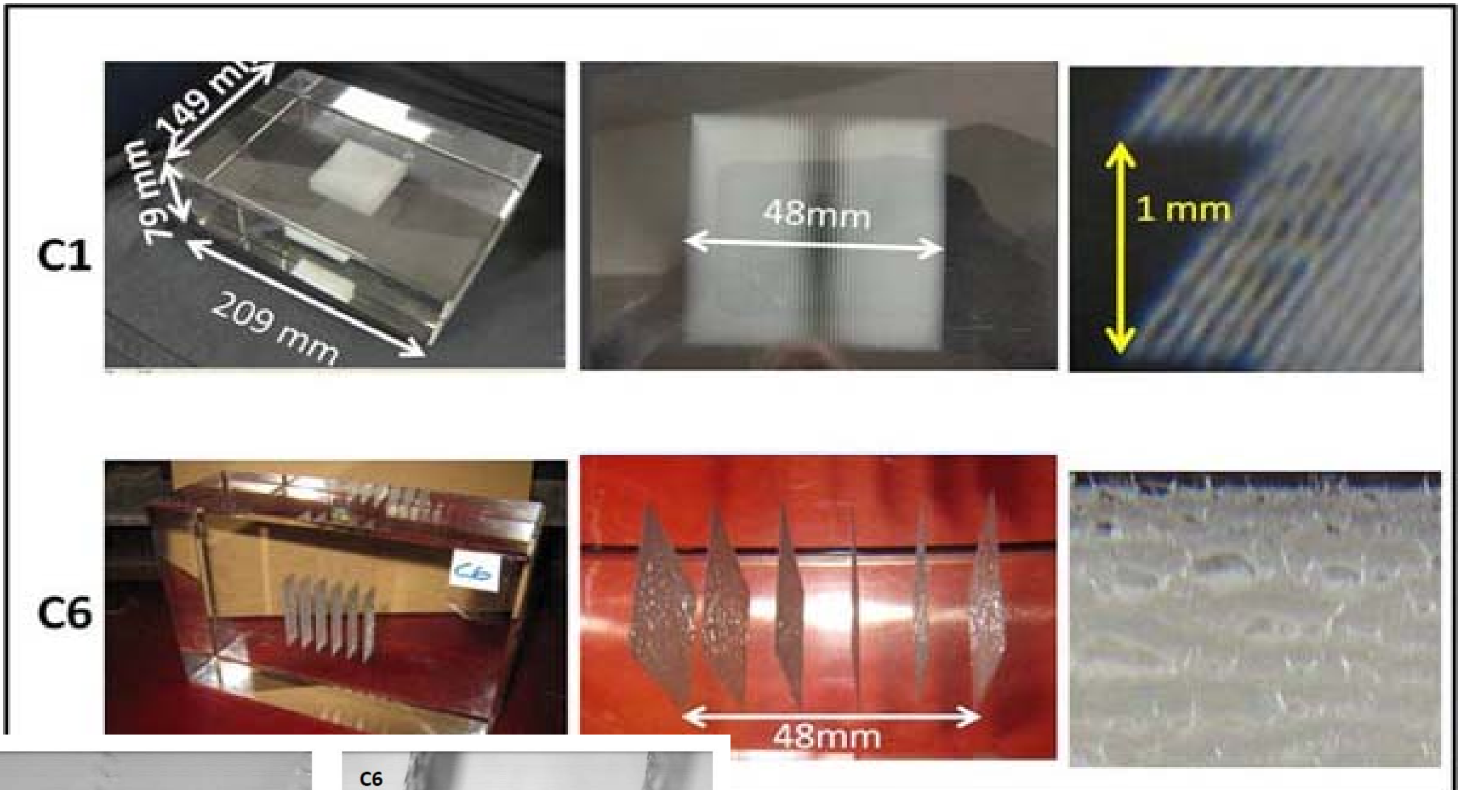


3D sub-surface laser etching (SSLE)

- How does it work?
  - Focused laser heats a small point in the optical-grade, lead-free glass to create a melted point or micro-crack
  - Non-adjoining microcracks form a point cloud and optical image
- Advantages
  - Very elastic, rock-type material; extremely high accuracy, digitally defined inclusions/fractures; complex models; design regime (e.g., wavelength/crack spacing)
- Trickiness
  - Overdriving or closely spacing points can create a larger fractures; unwanted signals

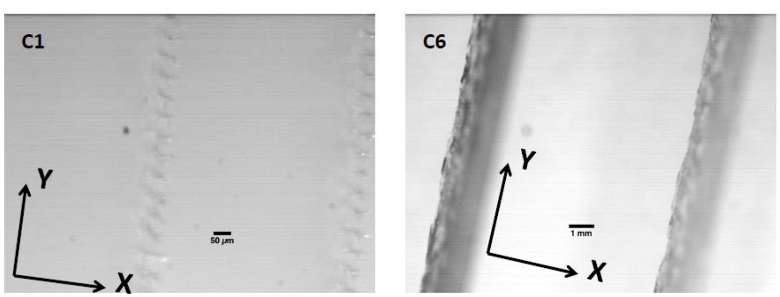


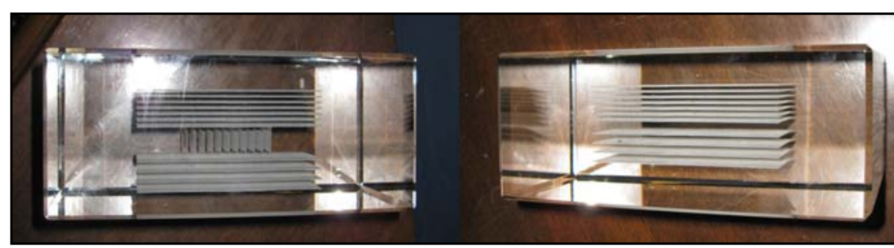
Laser-etched glass blocks



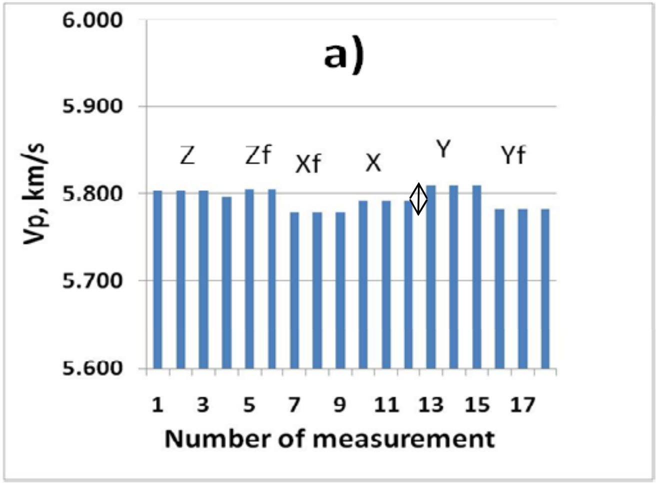
Fine point clouds

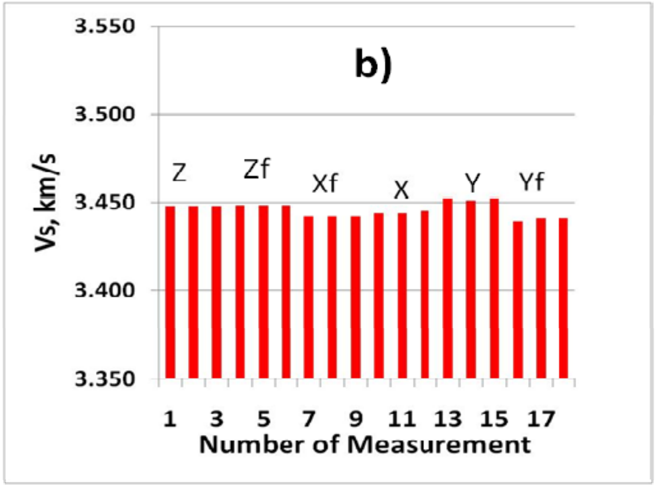
Intense cracking

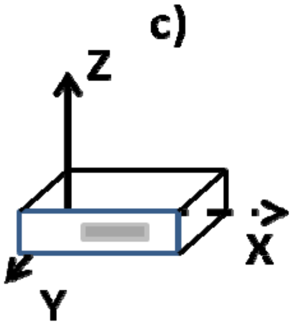




Transmission velocity values







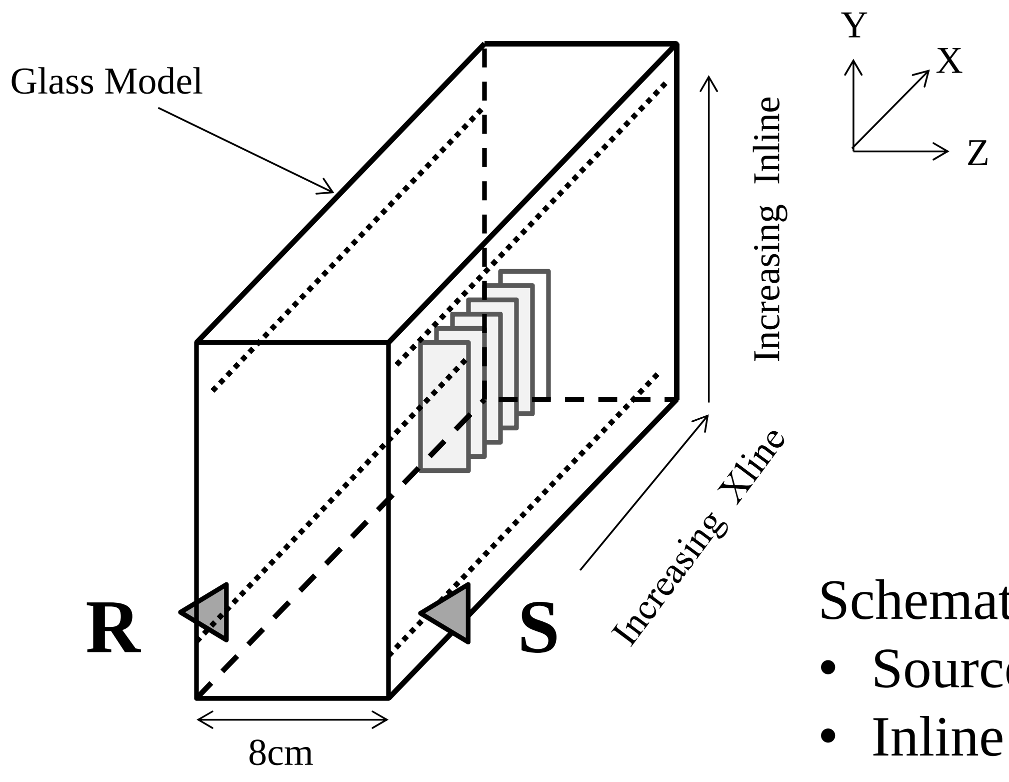
Vp/Vs = 1.68

Velocity errors approximately = 0.2%
(from distance error of 0.01mm and picking error of 20ns)
Background variability may be 0.5%

Fractures have a small effect on transmission velocities

Optical glass ~ 5900m/s (Li et al.,2010)
Vp=5920 m/s, Vs =3790m/s, Vp/Vs= 1.56 (SiO_2,Heiman et al., 1979)

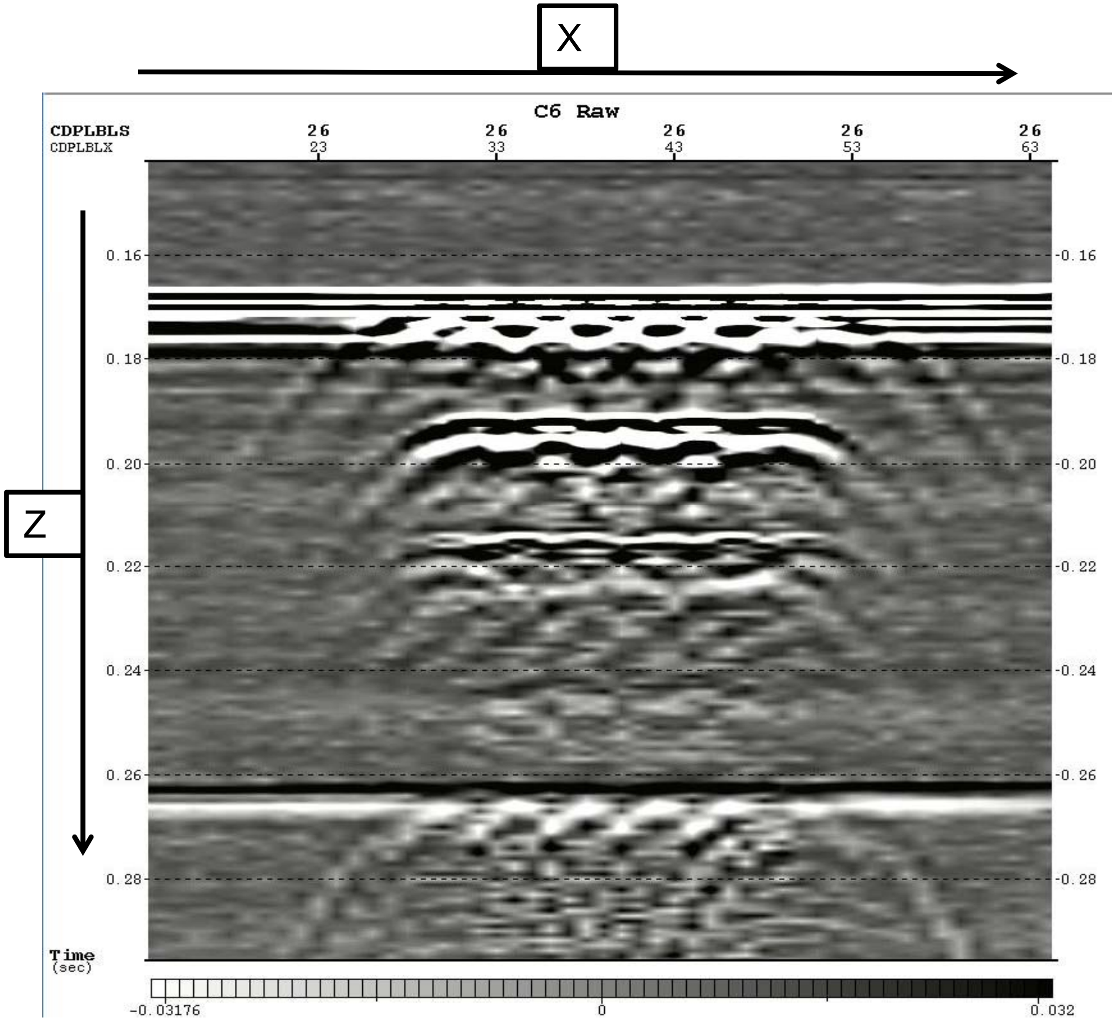
Experimental setup

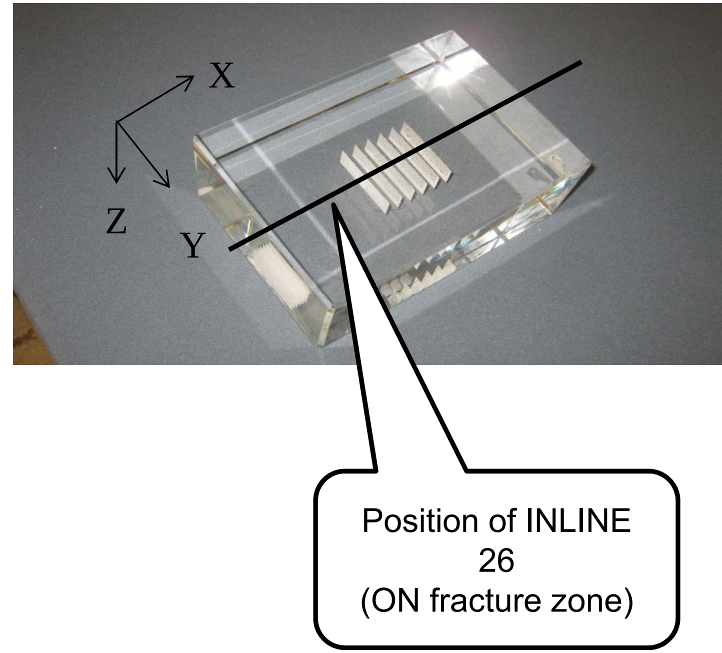


Schematic diagram of experimental setup

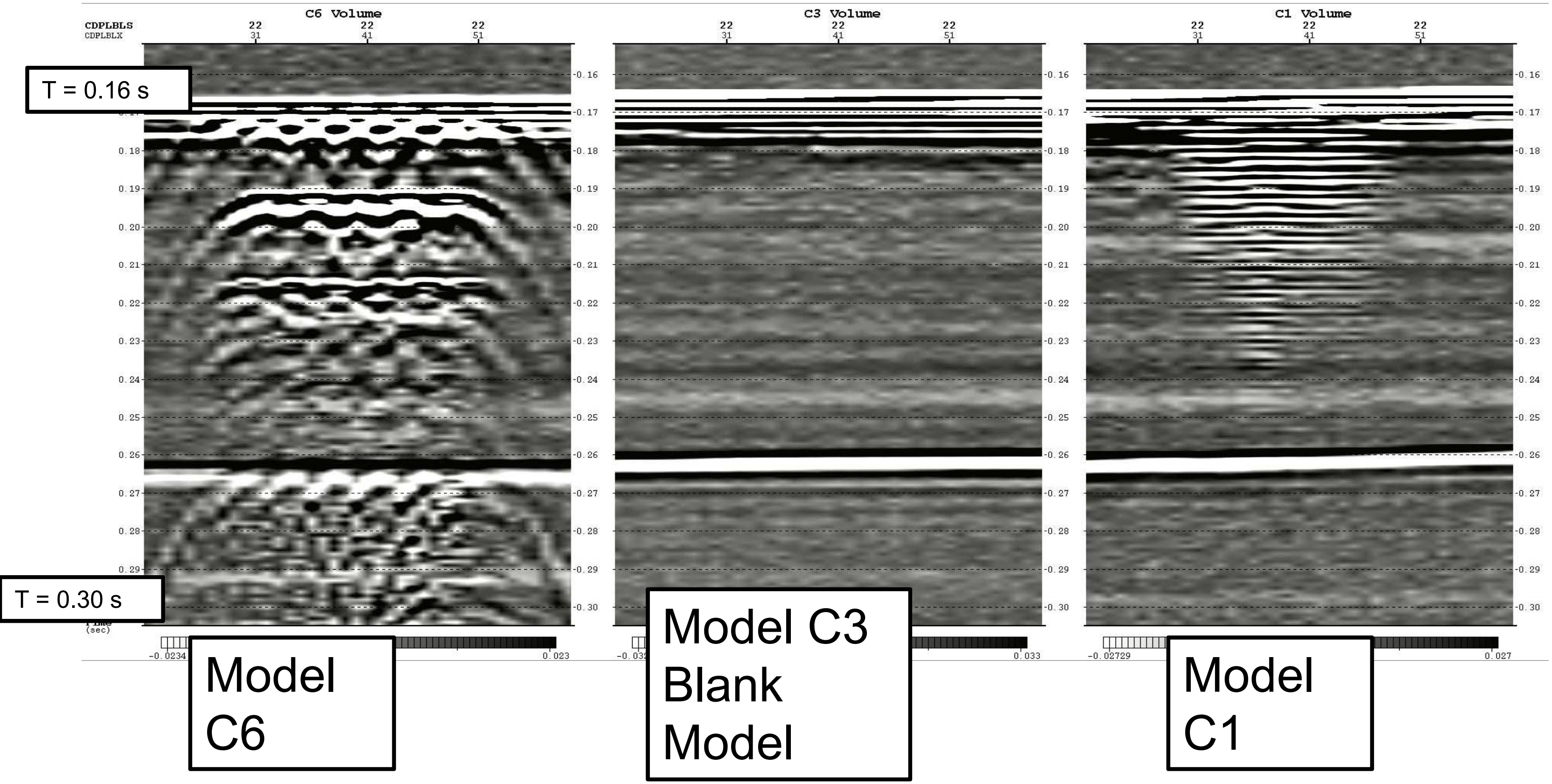
- Source and receiver on opposing sides
- Inline interval = 25m
- Xline interval = 25m
- # of Inlines = 52
- # of Xlines = 76
- Transducer Frequency = 5MHz
- Model dimension = 21 (Z) X 15 (Y) X 8 (Z) cm

- Transmission survey (5 MHz transducers)

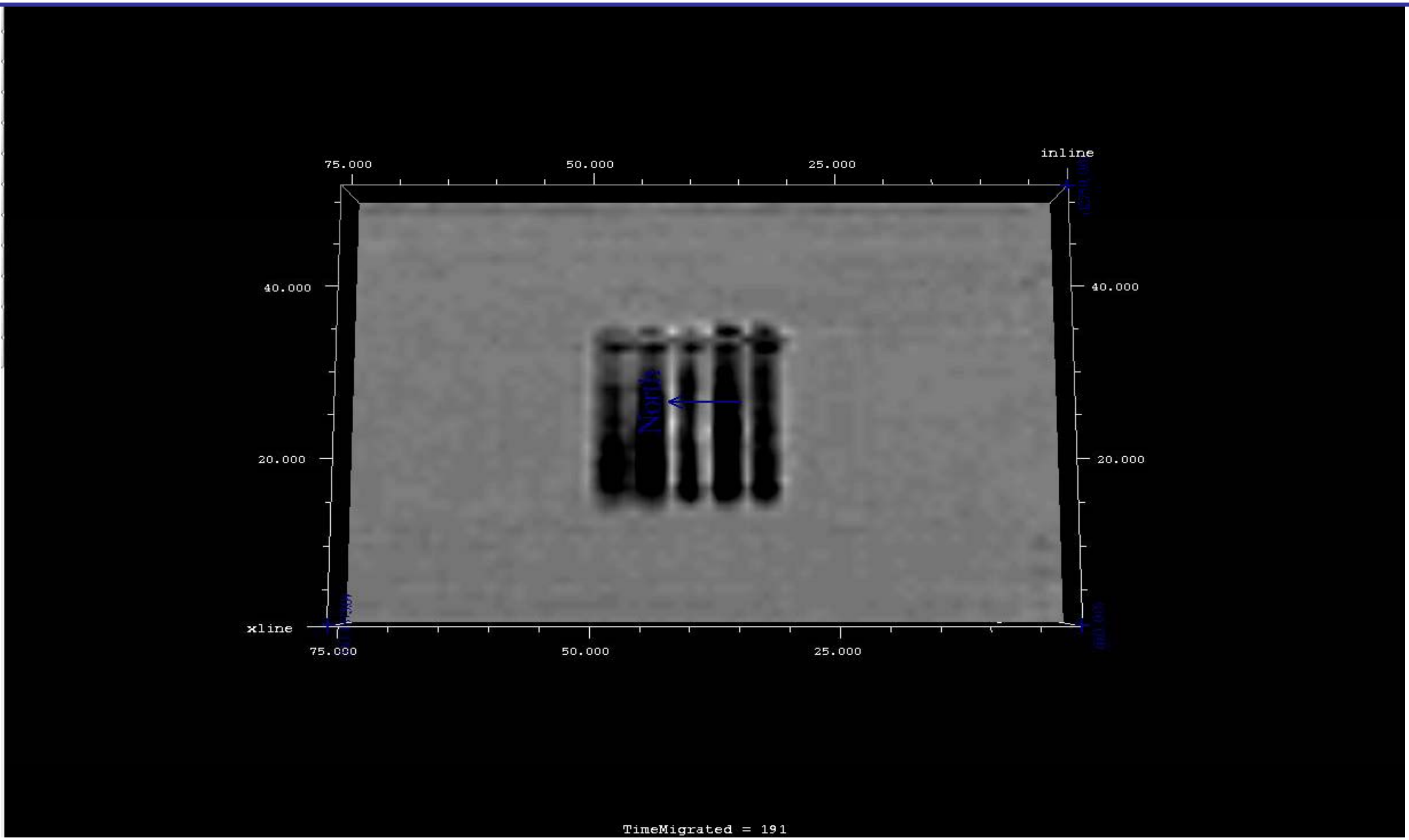




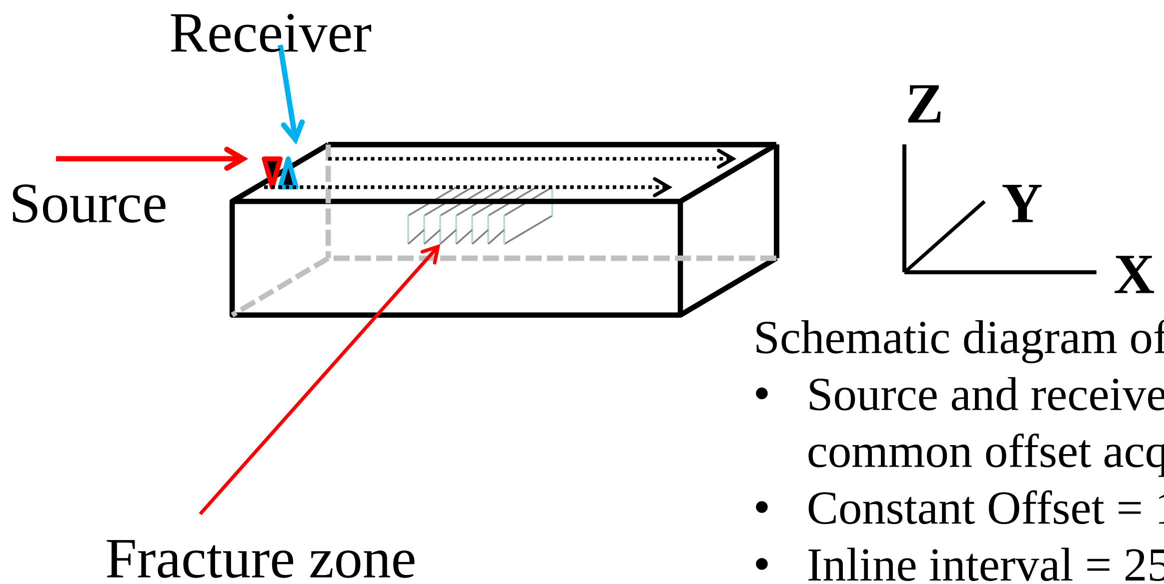
Zoom of Transmission Section (on fracture zone)



Post-stack migration of transmission data: time slice at 191 ms



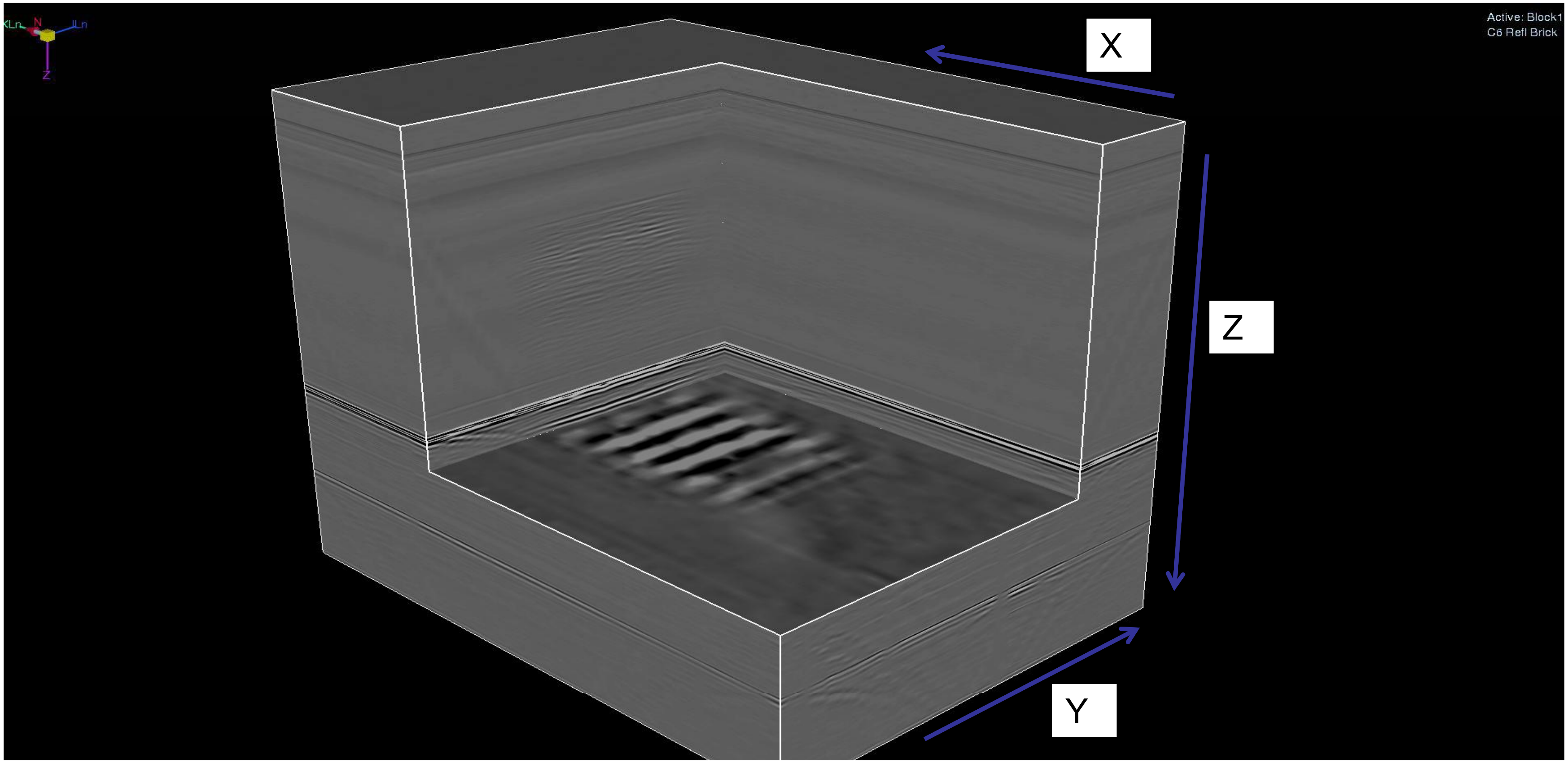
Experimental setup



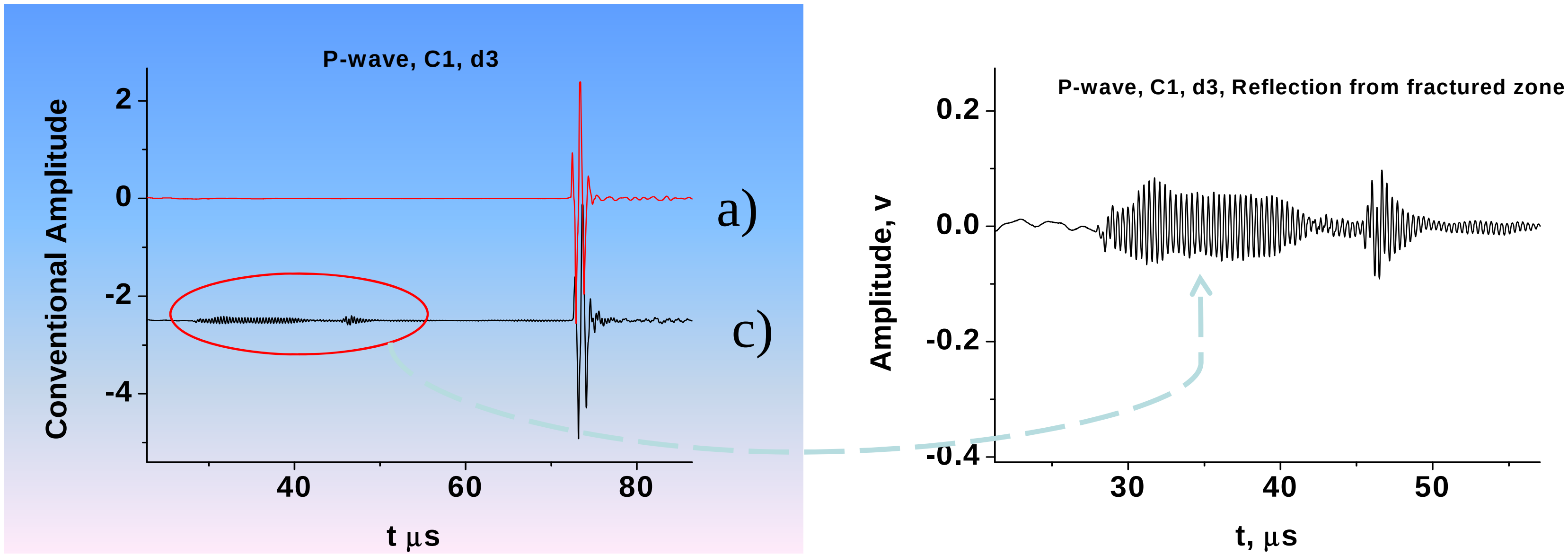
Schematic diagram of experimental setup

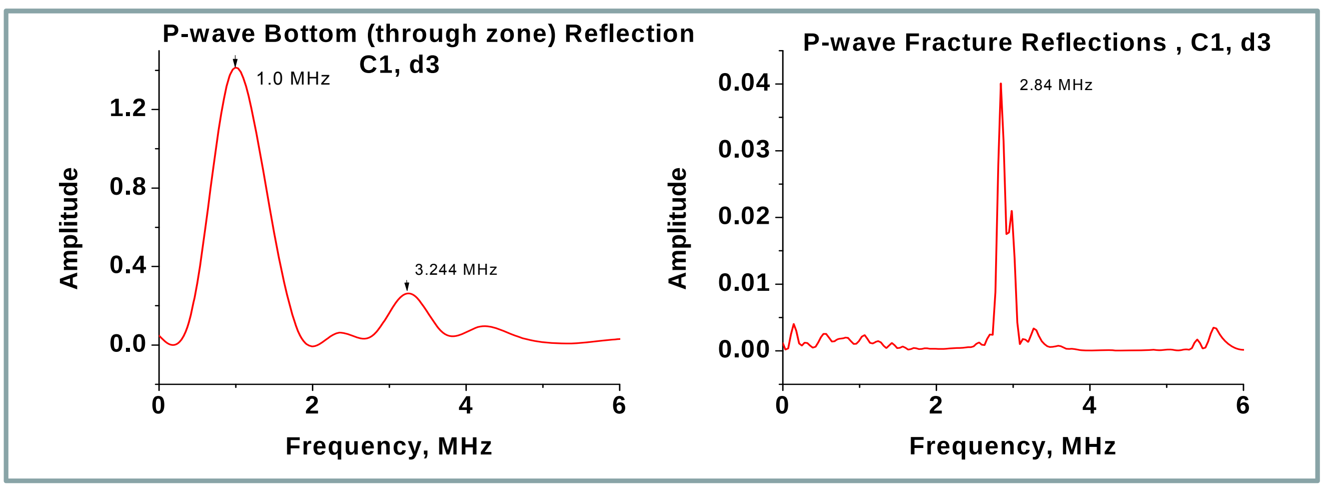
- Source and receiver on the surface for common offset acquisition
- Constant Offset = 13mm (130m)
- Inline interval = 25m
- Xline interval = 25m
- # of Inlines = 52
- # of Xlines = 71
- Transducer Frequency = 5MHz
- Model dimension = 21 (Z) X 15 (Y) X 8 (Z) cm

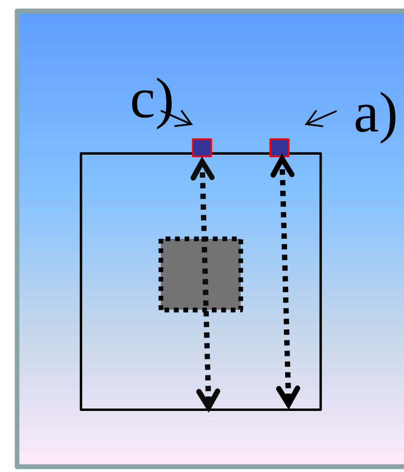
3D Reflection Volume Model C6



Comparison reflected signals and spectra for Glass C1



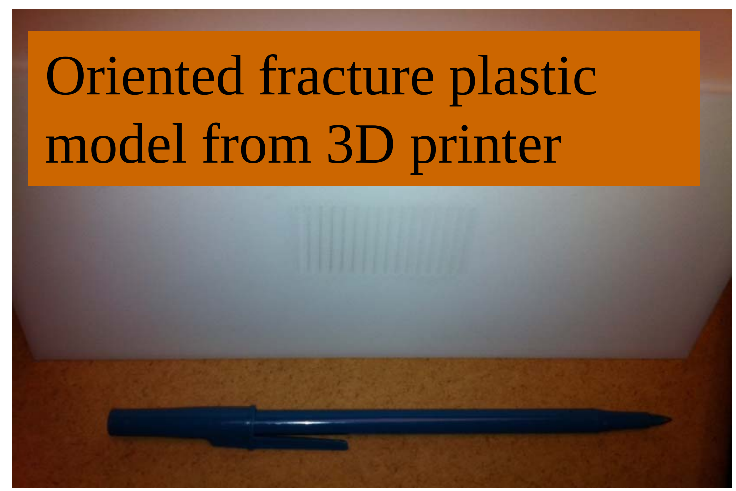




3D printing – exciting new technology for physical models

3D printer at UH

3D scanning and printing
(wikipedia.org, 2008)



Oriented fracture plastic model from 3D printer

Summary

- Two new exciting technologies for modeling : Laser-etched glass and 3D printed plastic
- Rich anisotropic response of models
- Anisotropy appears to be frequency dependent
- The coda wave exhibits scattering signature
- Physical modeling is useful & flexible for investigating simple through complex anisotropic domains
- Very promising results for imaging fractured regions and their characteristics

How much fuel is in the tank?

A framework for oil reserve estimation & likelihood using 3C-3D seismic data and well logs

Robert R. Stewart [1] and Henrique Fraquelli [2]

[1]Universities of Houston and Calgary; [2]U. of H. and Petrobras

CREWES Sponsors Meeting – Banff, December 2nd, 2011

Very approximate company valuation:
NAL Oil & Gas Trust (nae.un-t www.nal.ca)

West Texas Intermediate $87.41/barrel on Oct. 17, 2007

Price on Oct. 17, 2007: $12.80/share

~10-20 times earnings (Price/Earnings~15)

- $NetIncome/share (June '07) ≈ $1.00 → $15.00/share

~$60,000/flowing barrel per day

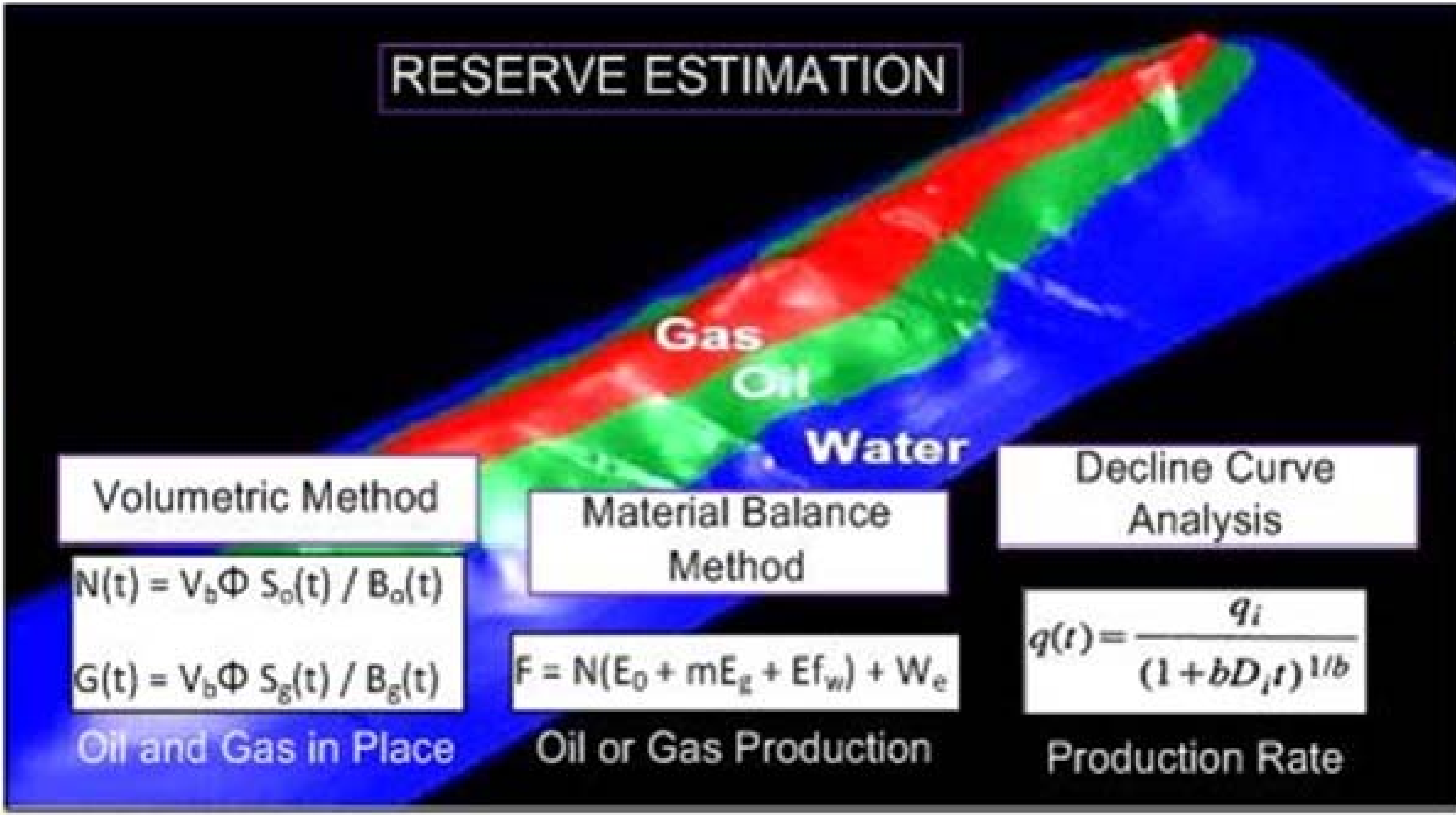
- 19,000boe/d → 1.14G$/79M shares = $14.40/share

~$20/BOE reserves

- 58Mboe (2006 proven+probable) → 1.16G$ or $14.70/share

~ 15% yield (Distributions of $1.92/share per year at $12.80)

Techniques to estimate reserves

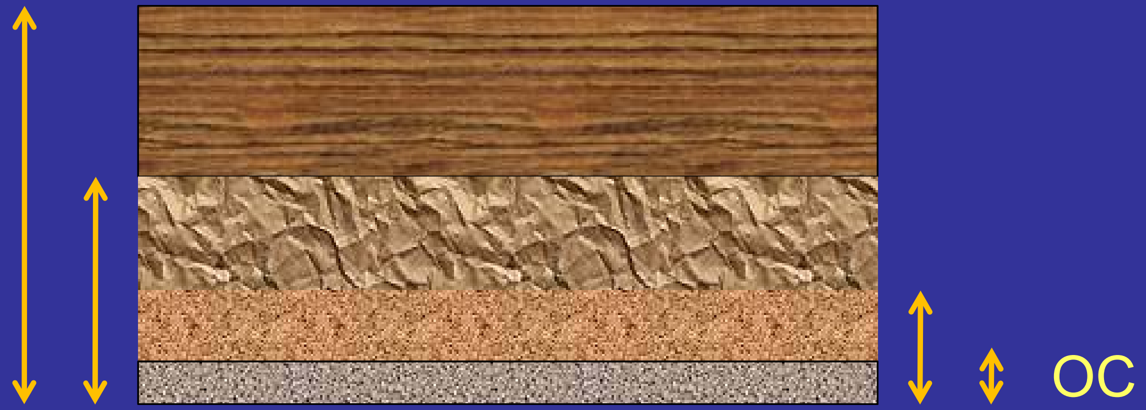


Accessed Feb. 6, 2011 http://reservestimation.blogspot.com/

Oil Column (OC) & Volume Calculation

OC = isopach • sand% • porosity • (1- Sw)

Volume = Area • OC



The Volumetric Method

Hydrocarbons in place in the reservoir

$$OOIP = \frac{7{,}758 \times A \times h \times \phi \times (1 - S_{wi})}{B_{oi}}$$

Murtha & Ross 2009

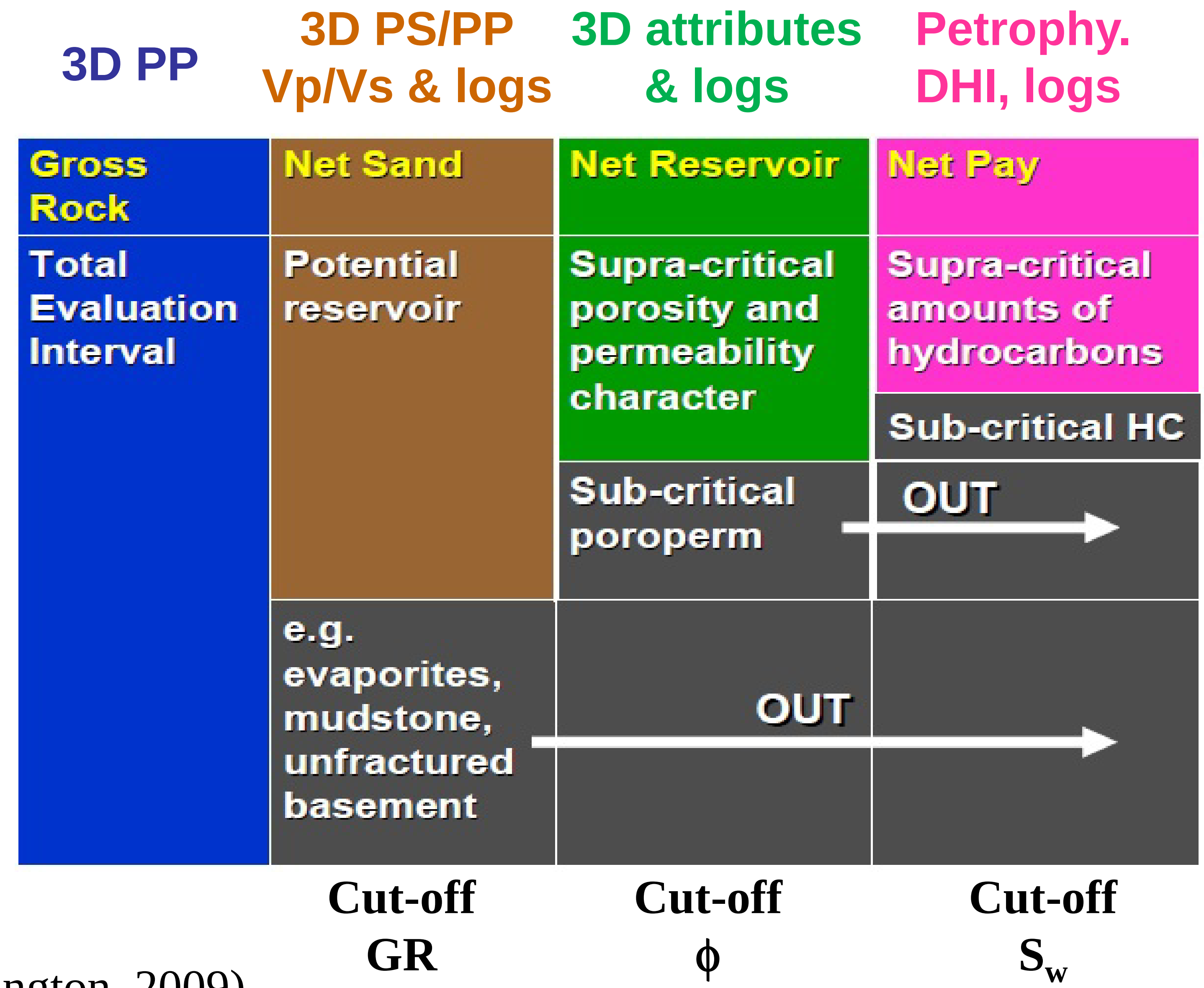
OOIP = Original oil in place

Our focus (HCPV)

A = Area (acres)
h = net pay thicknesss (ft)
ϕ = porosity (fraction)
S_{wi} = initial water saturation (fraction)
B_{oi} = initial oil formation volume factor (rb/stb)

$$HCPV = A \times h \times \phi \times (1 - S_{wi})$$

PRMS-AD 2011



(Worthington, 2009)

General estimation procedure

Well logs
and
3C seismic data

Well log & joint seismic interpretation
+
Seismic Inversion
+
Geostatistical methods

What's new here? – seismic error analysis; probability from errors

Thickness/isopach map

% sand map

porosity ϕ map

+ S_w (from logs)

HC column
$\times$
Area

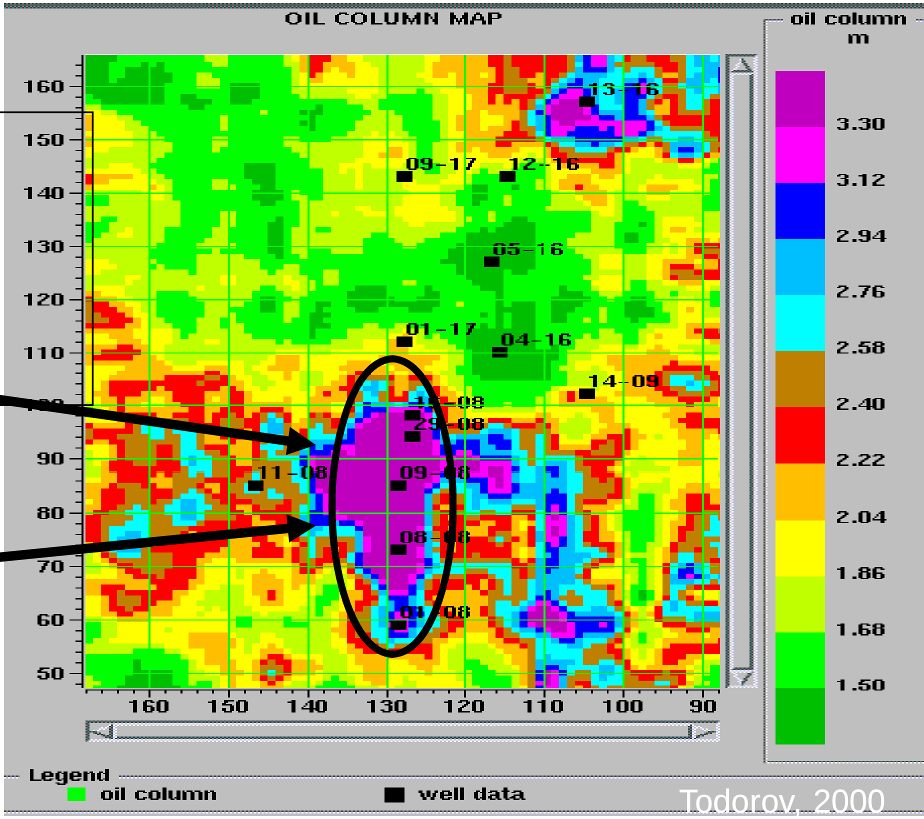
Hydrocarbon pore volume

Todorov & Stewart (2000)

Comparing results

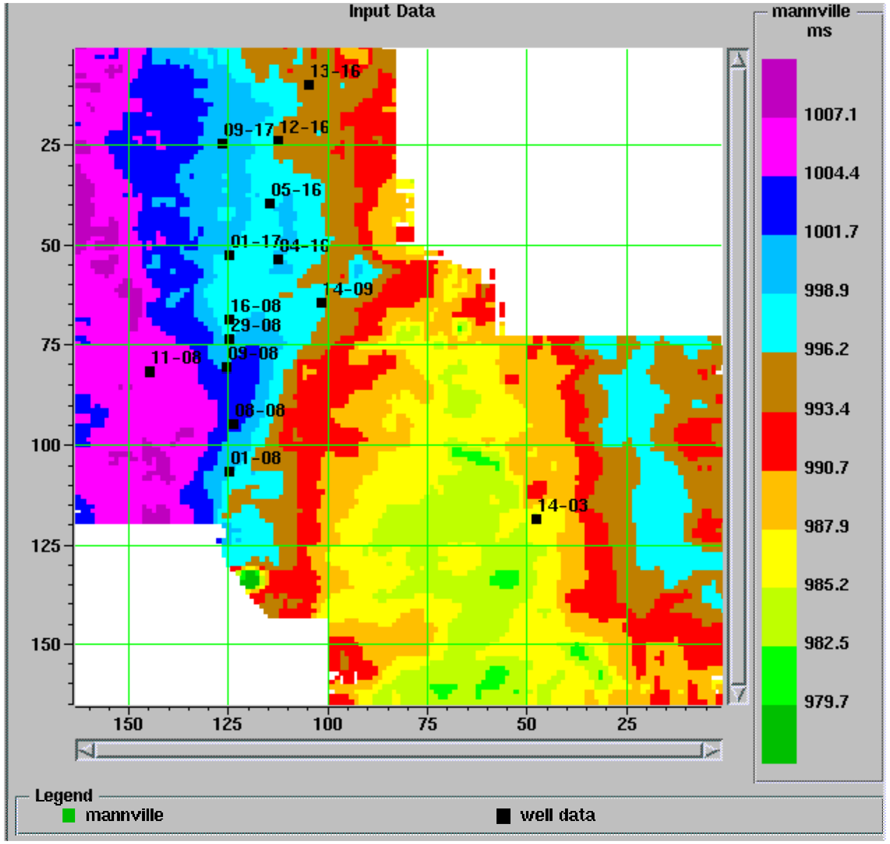
Encana (ex-PanCanadian)
Engineering - 2000
OV~ **8,553,040 bbl**

Seismic & Logs – T-S 2000
$OV_{T\text{-}S} \approx$ 8,220,000 bbl

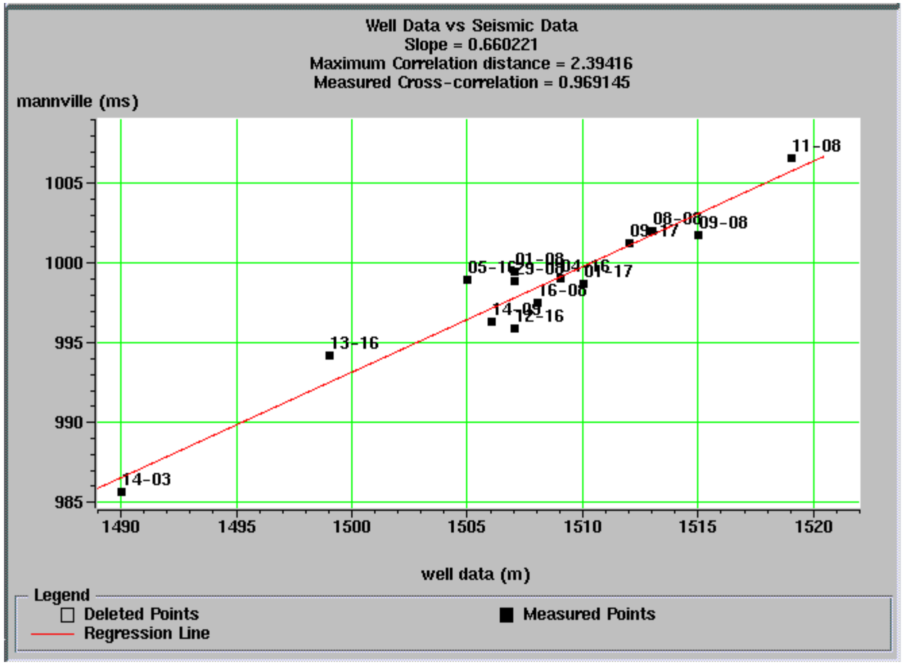


Blackfoot volume estimate in 2000 of OOIP
≈ 6,300,000 bbl **(Boi=1.3; Crain, 2010)**

Mannville time

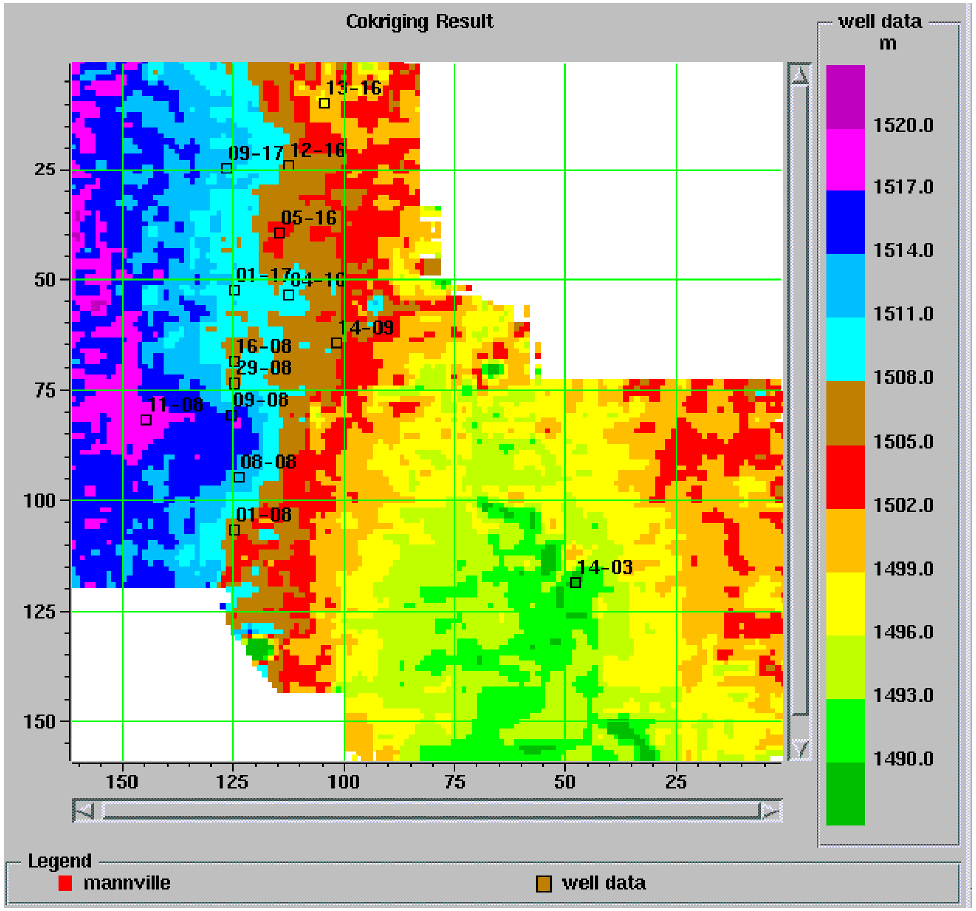


Time vs depth

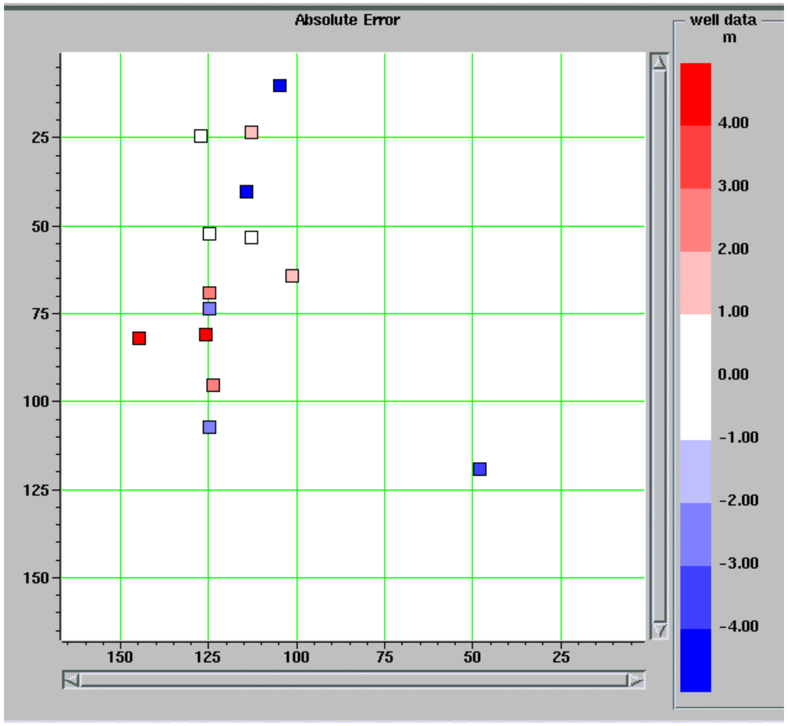


correlation: 0.96

Cokriging Mannville depth



Absolute error



(Thanks, Dan & Brian & CGGVeritas!)

1st Method of estimation of uncertainty in HCPV

Assuming independent measurements and errors, we find σ

Uncertainty in HCPV:

(Coleman & Steele, 19

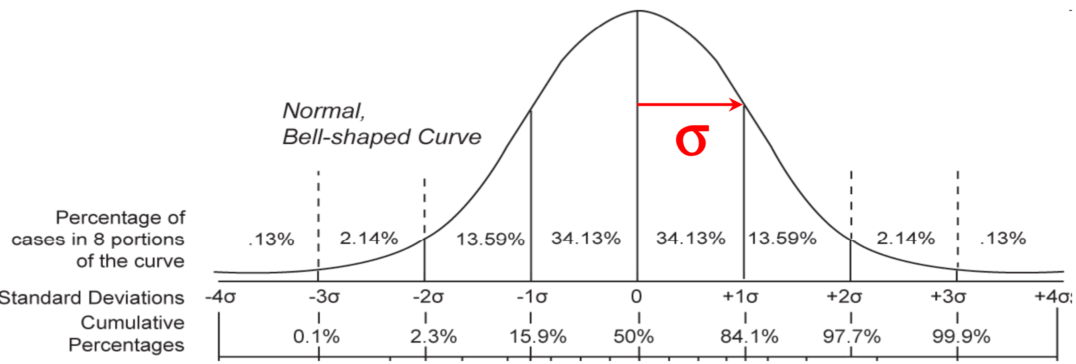
$$\left(\frac{\sigma_{HCPV}}{HCPV}\right)^2 = \left(\frac{\sigma_{thickness}}{thickness}\right)^2 + \left(\frac{\sigma_{\%\,sand}}{\%\,sand}\right)^2 + \left(\frac{\sigma_{\phi}}{\phi}\right)^2 + \left(\frac{\sigma_{S_{HC}}}{S_{HC}}\right)^2 + \left(\frac{\sigma_{Area}}{Area}\right)^2$$

Percentage error:
thickness = 6%
%sand = 10%
porosity = 11%
S_{HC} (from logs) = 10%
Area = 30%

$$\frac{\sigma_{HCPV}}{HCPV} \cong 0.35$$

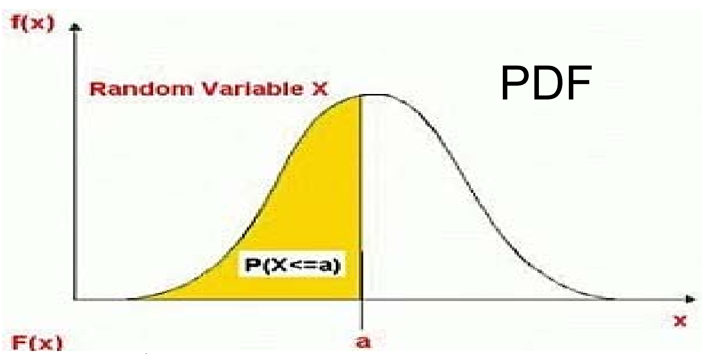
Uncertainty in the Oil Volume

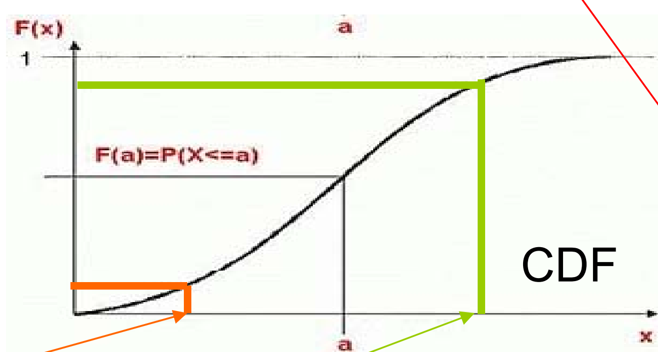
Exploring the PDF-CDF relationship



Relationship

(Mean,STD) ⟺ Probability





$$\frac{\sigma_{HCPV}}{HCPV} \cong 0.35$$

$$\sigma_{HCPV} \cong 0.35 \cdot HCPV$$

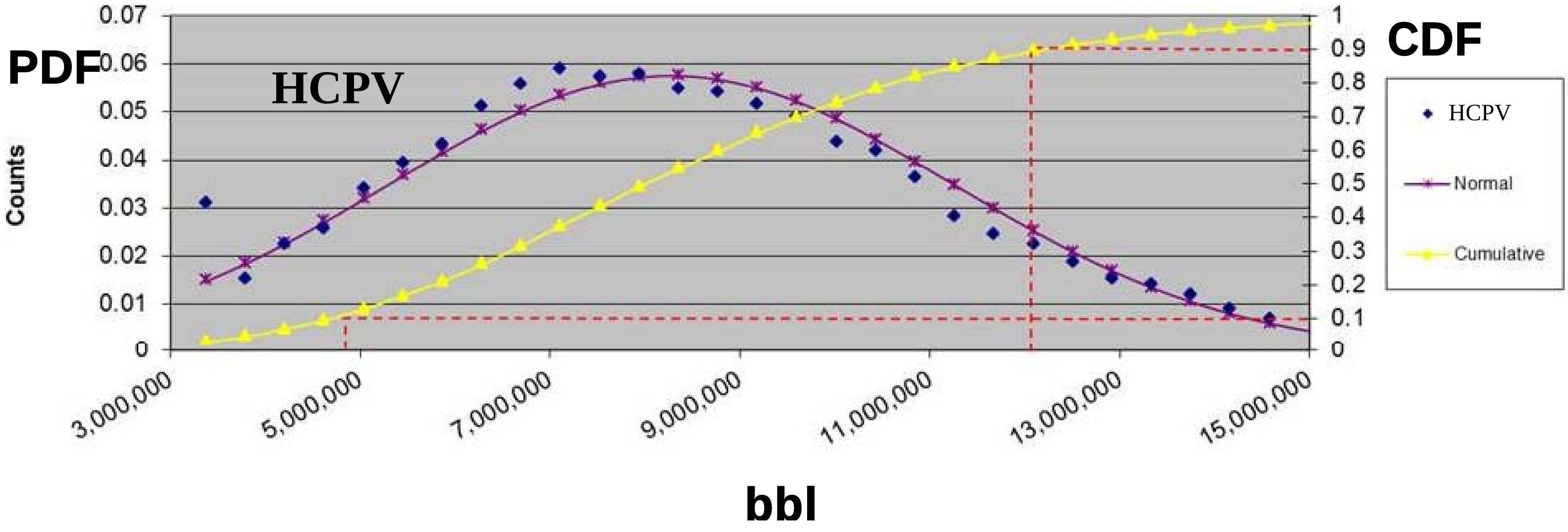
P_{90} = $0.706 \times OOIP_{TS} \approx$ 4,485,000 bbl

P_{10} = $1.294 \times OOIP_{TS} \approx$ 11,950,000 bbl

2^{nd} Method of estimation of uncertainty in HCPV

Monte Carlo approach

- HCPV = thickness $\times$ %sand $\times$ ϕ $\times$ $(1 - S_{wi}) \times$ Area
  Input PDFs assumed as normal distributions (defined by μ, σ)
- Uncertainty value in each parameter as before
- 10,000 simulations



BLACKFOOT OIL Pool - follow up.

You replied on 9/28/2011 9:10 PM.

Ken Mitchell [kenm@veroenergy.ca]

Sent: Wednesday, September 28, 2011 3:30 PM

To: rrstewart@uh.edu

That comes from a total of 11 wells - 8 current producers and 2 injectors.

Pool Information

Field:	BLACKFOOT
Pool:	U MANN A & GLAUC A
Effective Date:	August 1, 2003
Regulatory Code:	800160
OGCA Order:	N/A
Strike Area:	No
Commingled:	Yes

Wells:

Total	Producing	Cored	Injection
11	8	3	2

Well List

Production:

Pool Type: Oil and Gas

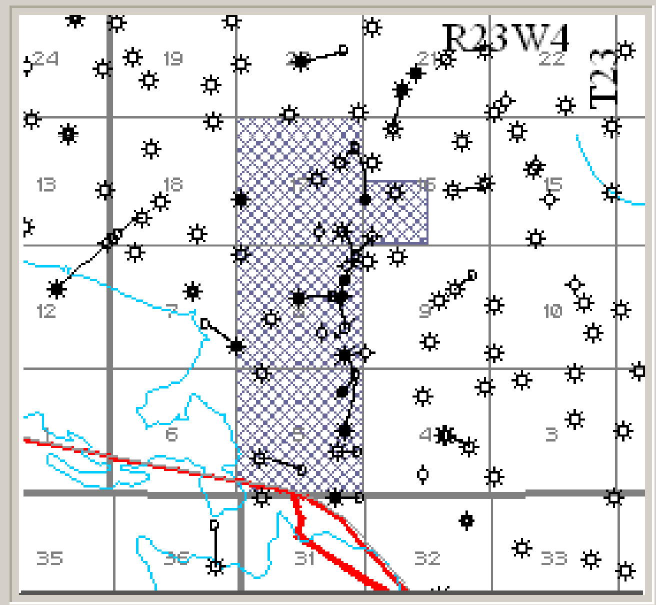
Production Status: Producing

	Calendar	Cumulative
Oil	149.069 bbl/d	907.533 mbbl
Gas	526.383 mcf/d	3188.302 mmcf
Water	89.046 bbl/d	387.707 mbbl

	Avg. GOR	Avg. WOR
Ratios:	3513.153 scf/bbl	0.427 bbl/bbl

Imp SI Reserves Group Plot

Map:



Pool: 6 of 9

Prev Next

BLACKFOOT OIL Pool - follow up.

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Ken Mitchell [kenm@veroenergy.ca]

Sent: Wednesday, September 28, 2011 3:30 PM

To: rrstewart@uh.edu

Oil Reserves (as of Jun 2011)

Field: **BLACKFOOT (138)**
Pool: **U MANN A & GLAUC A (800160)**
Pool Discovery Location: **00/09-08-023-23W4/0**
Discovery Year: **1994**

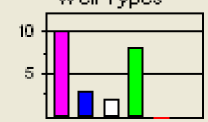
Pool Type: WATER FLOOD
Pool Class: **Unknown**

Close | Preview | Print

General Data

Total Wells:	**10**	Oil Wells:	**8**	Area:	**266.9 ac**
Cored Wells:	**3**	Gas Wells:	**0**	Spacing:	**26.7 ac/well**
Injection Wells:	**2**	Aband. Wells:	**0**		

Well Types



Production Data

OOIP: **5,500.0 mbbl**

Pri. ROIP, (pRF): **550.0 mbbl(0.1000)**
+Enh. ROIP, (eRF): **550.0 mbbl(0.1000)**

Tot. ROIP, (tRF): **1,101.3 mbbl(0.2000)**

Avg. GOR: **3,513.15 scf/bbl**
Cur. GOR: **3,283.05 scf/bbl**
Avg. WOR: **0.43 bbl/bbl**
Cur. WOR: **6.12 bbl/bbl**

Avg. GOR Inc.: **0.93x**

Driving force: **Unknown**
Calc. method: **Unknown**

Oil Prod. From Pool: **881.0 mbbl**
Pool Rec. Factor: **0.8000**

Cum. Oil Production: **907.5 mbbl**
Rec. Factor to date: **0.8241**

IP Date: **August 1994**

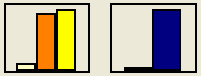
Water/Day: **89.05 bbl/d**
Gas/Day: **526.38 mcf/d**
Oil/Day: **149.07 bbl/d**

Reserves

Rec: 82.41 %
Cum: 907.5 mbbl
Rem: N/A
Enh: 193.7 mbbl
UnRc: 4,398.7 mbbl
RF: 20.00 %

OOIP:
5,500.0 mbbl

GOR WOR



Injection Data

Est. Voidage Replacement: **302.80 %**

Total Injected Gas: **0.00 mcf**
Total Injected Water: **3,921.99 mbbl**

Units
- (•) Imperial
- ( ) Metric

Production | Reservoir

Summary

- **Outlined a framework for oil volume estimation from geophysical data**
- **Geostatistics are important for depth, thickness, lithology, & porosity determination**
- **PS seismic data useful in lithology & porosity estimation**
- **Cross-validation tests find meaningful attributes**
- **Compelling methodology for basic volume estimates**

- Digging deeper into errors: Survey design, S/N, picking errors, Vp/Vs
- Use petrophysics, logs, & seismic for Sw in geostat framework
- Use attributes: Q then viscosity with T,P then Sg then B_{oi}