The University of Oklahoma
MEWBOURNE COLLEGE OF EARTH & ENERGY

Shales Moving Forward

Moore Norman Technology Center
Norman, Oklahoma

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Microseismic Frac Mapping: Moving Beyond the Dots from an Engineering Perspective

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Chief Engineer

Outline

- Microseismic 101
- A glance in the rear view mirror
- The engineer’s fracture diagnostics toolbox
- Why engineer’s use microseismic monitoring
- Microseismic technology advancements
- “Unconventionals” have changed the game
- What’s missing? – Moving Beyond the Dots
- Value addition opportunities
- What’s Next?

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Microseismic 101

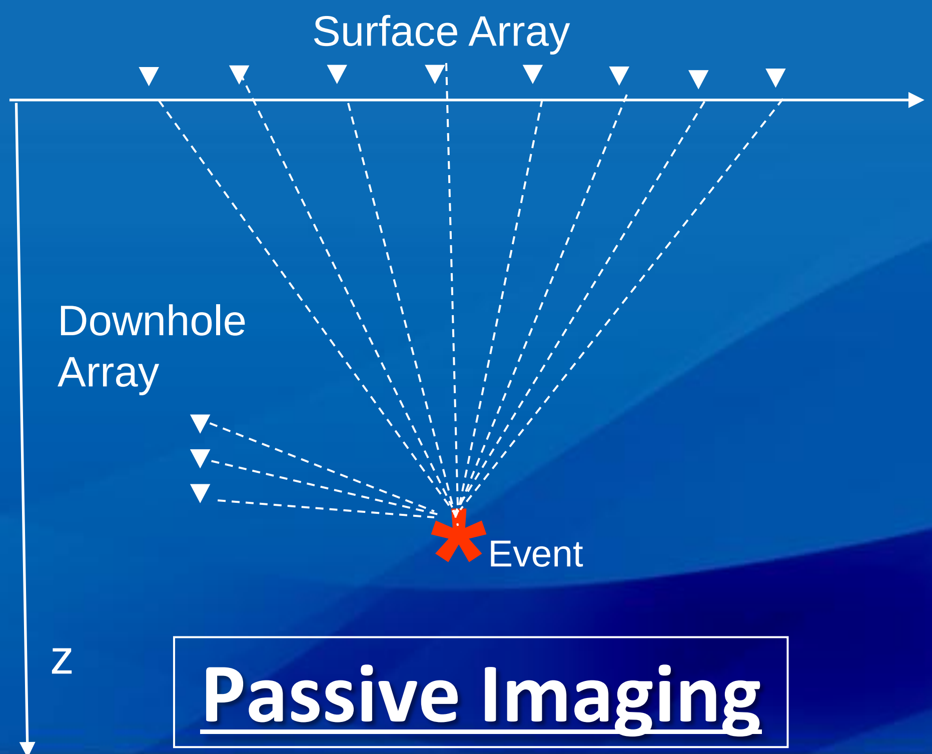
- Practice of listening to **passive**, microseismic activity caused by **hydraulic fracturing** (reservoir subsidence, and water, steam, or CO2 injection or sequestration).
- Microseisms are seismic energy emissions generated by shear slippages along weakness planes in the earth
- Passive Imaging is seismic without sources – receivers only

Objective:

• Detect and locate microseismic events in time and space.

•Measure characteristics of events (magnitude, source mechanism, etc.)

• Provide diagnostic information about the hydraulic fracture



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A Glance in the Rearview Mirror

- **1860** – Nitroglycerin injection used to stimulate shallow oil well in Pennsylvania (precursor to fracing?)

1947 - Stanolind Oil conducted the first experimental fracturing in the Hugoton field located in southwestern Kansas. The treatment utilized napalm (gelled gasoline) and sand from the Arkansas River. (1)

- **1949** - Halliburton conducted the first two commercial hydraulic fracturing treatments in Oklahoma (1)
- **1950's through 1980's** – Numerous hydraulic fracturing pumping and diagnostics technology developments
- **1992** - Pinnacle Technologies introduced surface tilt frac mapping
- **Late 1990's and early 2000's** – Pinnacle Technologies introduced downhole tilt and microseismic frac mapping
- **2003** - MicroSeismic, Inc. introduced surface microseismic frac mapping
- **2008** - MicroSeismic, Inc. introduced BuriedArray™ microseismic frac mapping
- **Over 1.1 million hydraulic fracture stimulation jobs in the past 6 decades**
- **Less than 2% of these jobs monitored using frac mapping technology**

(1) SPE JPT, December 2010; Hydraulic Fracturing – The Fuss, The Facts, The Future

The Engineer's Fracture Diagnostics Toolbox

Pinnacle Technologies

Stimulation Evaluation Tools

Will Determine / May Determine / Can Not Determine

GROUP	DIAGNOSTIC	MAIN LIMITATIONS	ABILITY TO ESTIMATE: Length	Height	Width	Azimuth	Dip	Volume	Conductivity
Indirect	Net Pressure Analysis	Modeling assumptions from reservoir description	May Determine	May Determine	May Determine	Can Not Determine	Can Not Determine	May Determine	May Determine
Indirect	Well Testing	Need accurate permeability and pressure	May Determine	Can Not Determine	May Determine	Can Not Determine	Can Not Determine	Can Not Determine	May Determine
Indirect	Production Analysis	Need accurate permeability and pressure	May Determine	Can Not Determine	May Determine	Can Not Determine	Can Not Determine	Can Not Determine	May Determine
Direct, near-wellbore	Radioactive Tracers	Depth of investigation 1'-2'	Can Not Determine	May Determine	May Determine	May Determine	May Determine	Can Not Determine	Can Not Determine
Direct, near-wellbore	Temperature Logging	Thermal conductivity of rock layers skews results	Can Not Determine	May Determine	Can Not Determine	Can Not Determine	Can Not Determine	Can Not Determine	Can Not Determine
Direct, near-wellbore	HIT	Sensitive to i.d. changes in tubulars	Can Not Determine	Can Not Determine	Can Not Determine	Can Not Determine	Can Not Determine	Can Not Determine	May Determine
Direct, near-wellbore	Production Logging	Only determines which zones contribute to production	Can Not Determine	May Determine	Can Not Determine	Can Not Determine	Can Not Determine	Can Not Determine	Can Not Determine
Direct, near-wellbore	Borehole Image Logging	Run only in open hole – information at wellbore only	Can Not Determine	Can Not Determine	Can Not Determine	May Determine	May Determine	Can Not Determine	Can Not Determine
Direct, near-wellbore	Downhole Video	Mostly cased hole – info about which perfs contribute	Can Not Determine	May Determine	Can Not Determine	Can Not Determine	Can Not Determine	Can Not Determine	Can Not Determine
Direct, near-wellbore	Caliper Logging	Open hole, results depend on borehole quality	Can Not Determine	Can Not Determine	Can Not Determine	May Determine	Can Not Determine	Can Not Determine	Can Not Determine
Direct, Far Field	Surface Tilt Mapping	Resolution decreases with depth	May Determine	May Determine	Can Not Determine	Will Determine	Will Determine	Will Determine	Can Not Determine
Direct, Far Field	DH Offset Tilt Mapping	Resolution decreases with offset well distance	Will Determine	Will Determine	May Determine	May Determine	May Determine	May Determine	Can Not Determine
Direct, Far Field	Microseismic Mapping	May not work in all formations	Will Determine	Will Determine	Can Not Determine	Will Determine	May Determine	Can Not Determine	Can Not Determine
Direct, Far Field	Treatment Well Tiltmeters	Frac length must be calculated from height and width	May Determine	Will Determine	Will Determine	Can Not Determine	Can Not Determine	Can Not Determine	Can Not Determine

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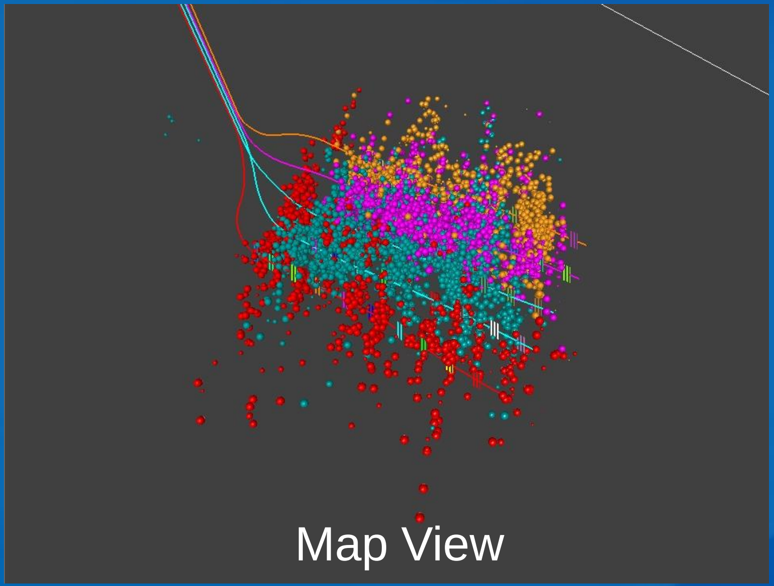
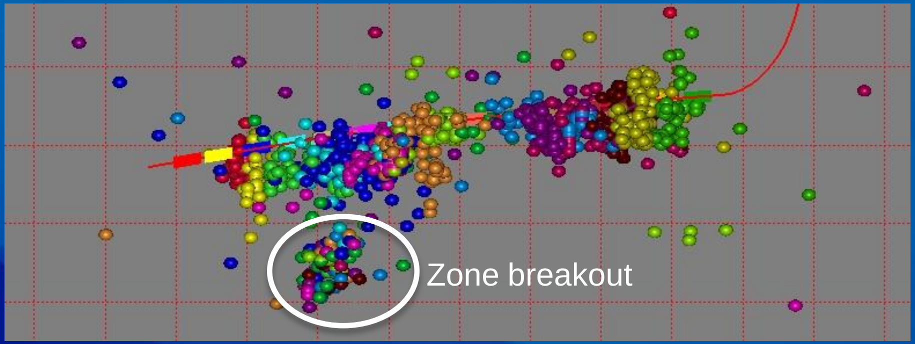
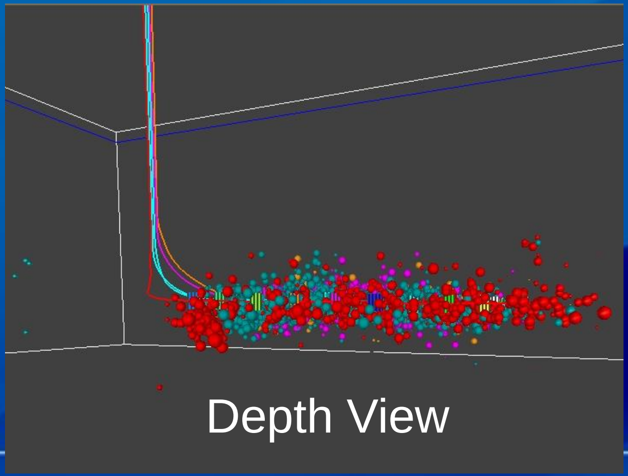
Why engineer’s use microseismic monitoring

- Diagnostic tool to better understand hydraulic fracture geometry
  - Length
  - Height
  - Azimuth
  - Complexity
- Identify patterns of hydraulic fracture development
  - Zonal containment or lack thereof
  - Well to well or stage to stage overlap
- Geohazard avoidance
- Estimate stimulated reservoir volume
- Fracture treatment refinement
- Long-term field development optimization







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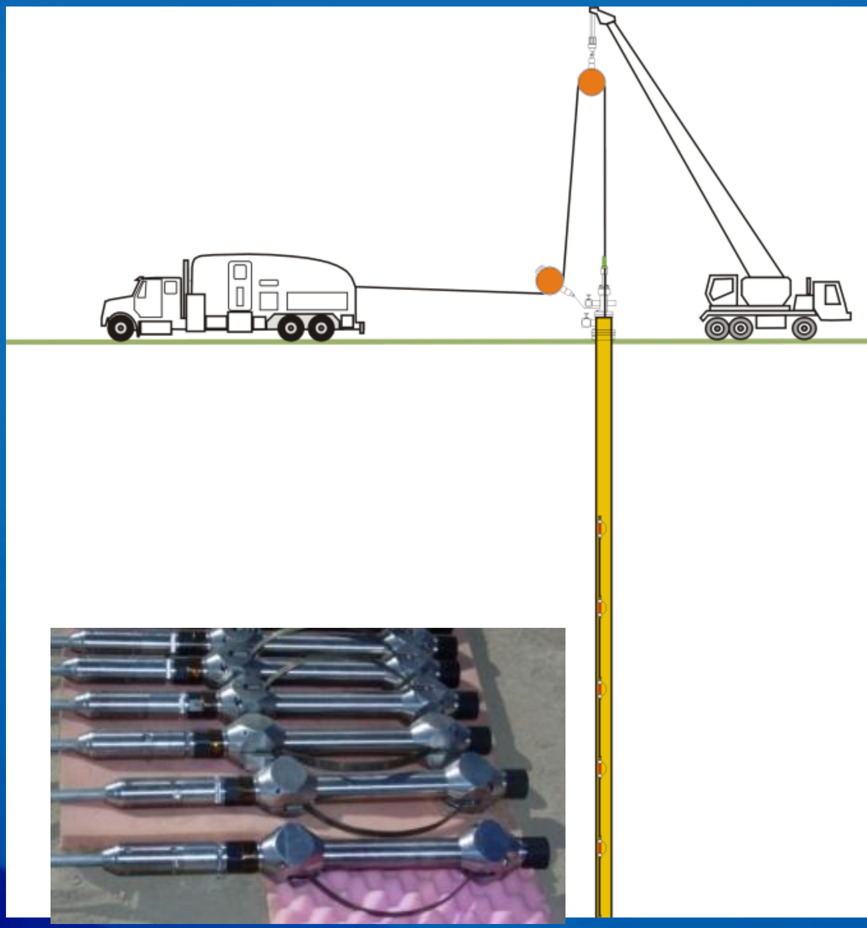
Technology Advancements - Downhole

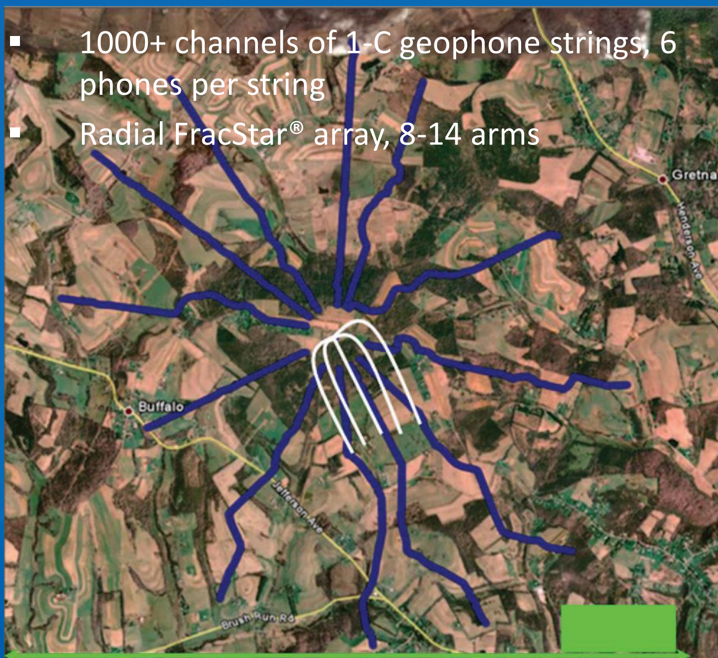


- Stacked arrays
- Expanded arrays
- Fiber-optic wireline

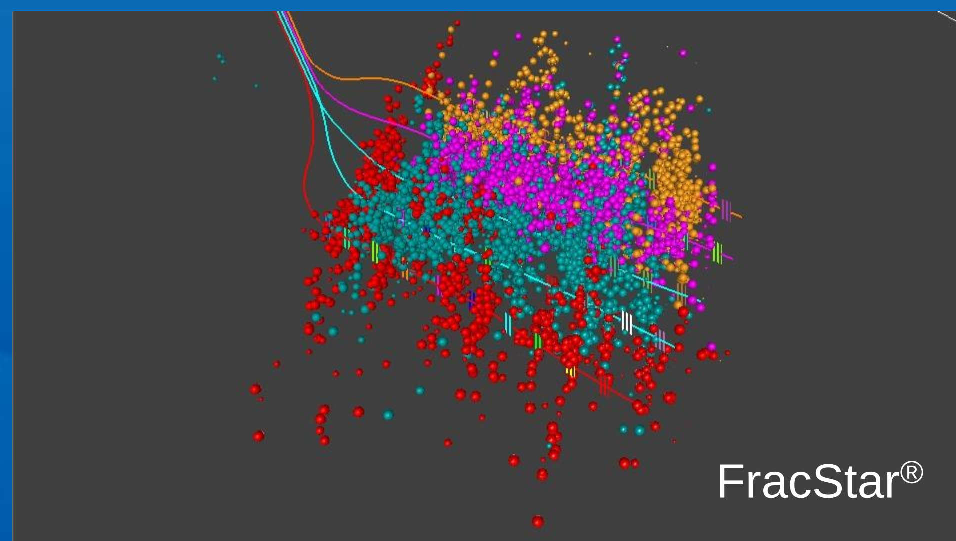
Technology Advancements - Surface

FracStar® Array

- 1000+ channels of 1-C geophone strings, 6 phones per string
- Radial FracStar® array, 8-14 arms



- Array Type — Surface
- Duration — Temporary
- Coverage area — ~3 to 7 Sq. Miles
- Capabilities — Frac Monitoring



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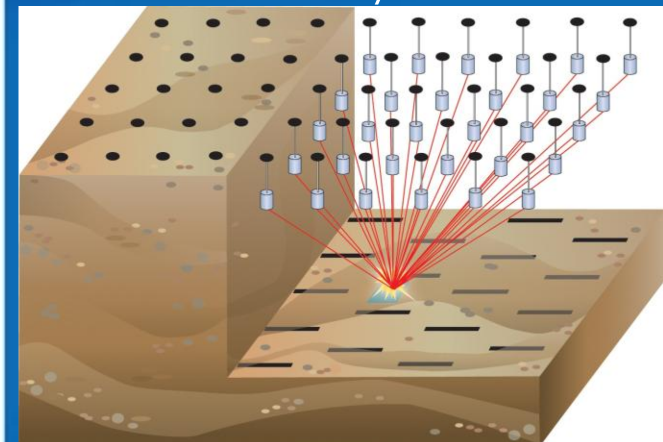
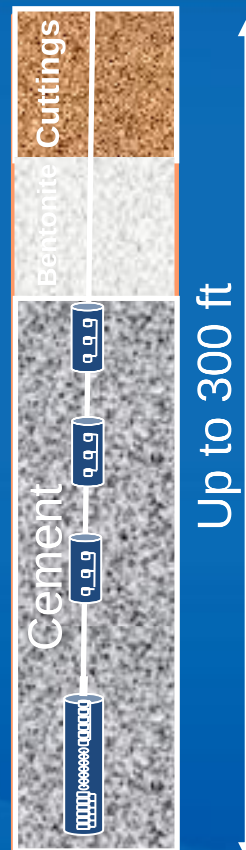
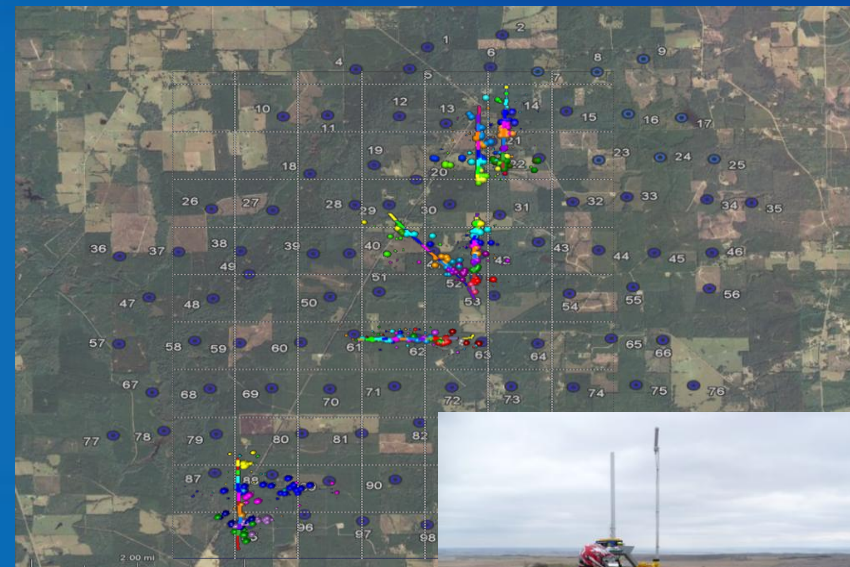
Technology Advancements – Buried Array™

BuriedArray™



- Array Type — Sub-Surface
- Duration — Permanent
- Coverage area — Hundreds of Sq. Miles
- Capabilities — Frac Monitoring; Reservoir Monitoring
- Buried — 50-300'





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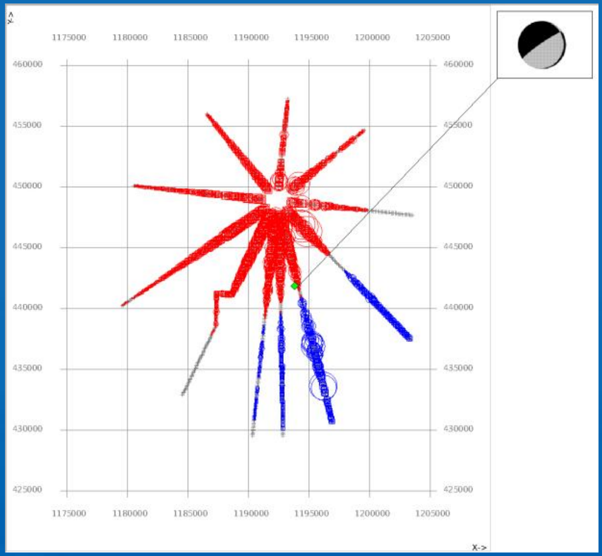
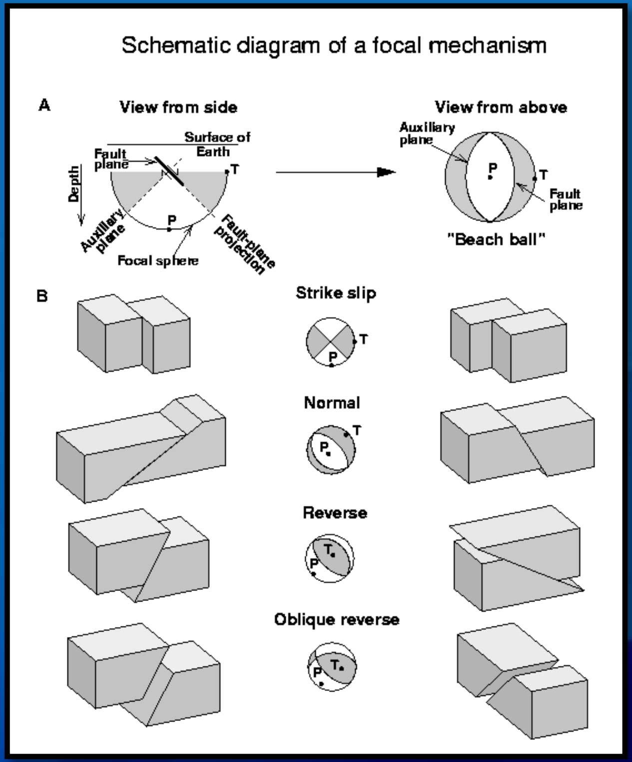
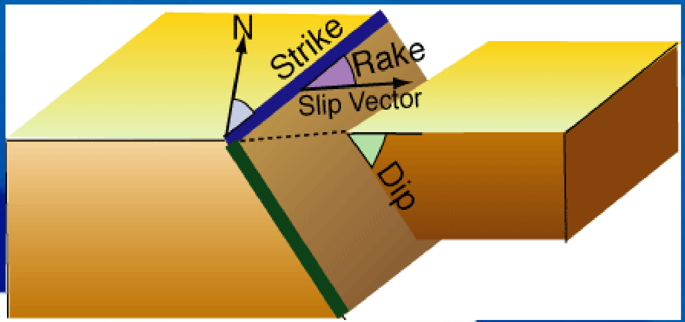
Technology Advancements - Processing

- Improved event detection capability and location accuracy
- Detailed source analyses – better understanding of how rock is breaking







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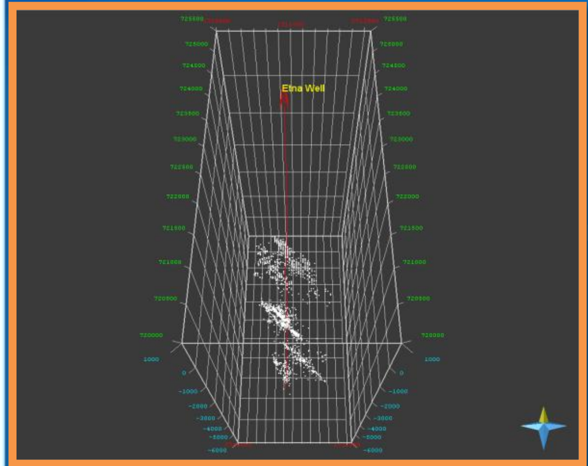
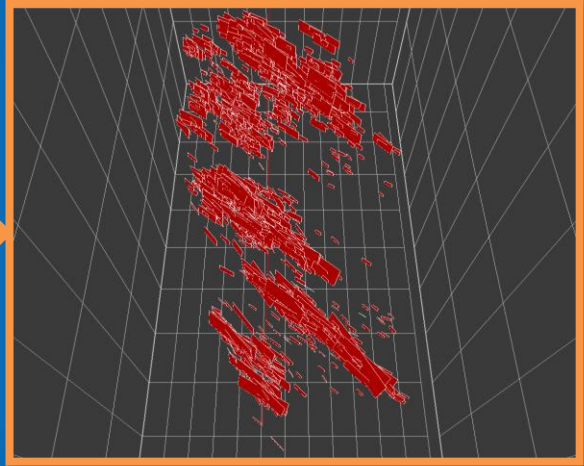
Technology Advancements – Visualization

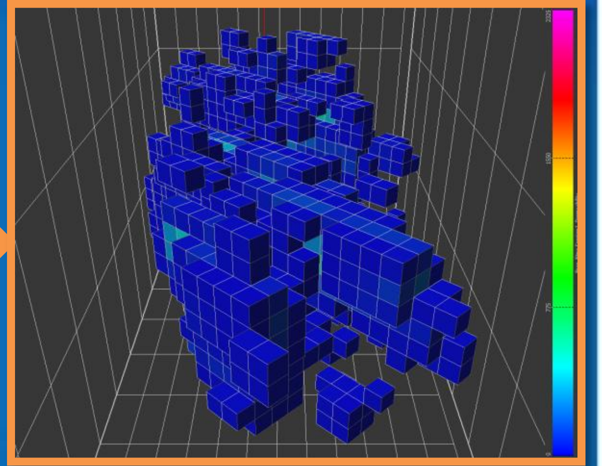
Well and Events



Discrete Fracture Network



Stimulated Reservoir Volume



- Layered permeability distribution
- Average fracture aperture - ft
- Average fracture porosity - unitless
- Total fracture volume (ft^3) – sum of fracture volumes in the model
- Stimulated reservoir volume (ft^3) – volume of geocellular cubes that have fracture properties (the affected rock matrix)

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Unconventionals are Changing The Game

Barnett widespread development began in 2003. Horizontal wells and hydraulic fracturing were the key enablers. Other unconventional plays followed on the heels of the Barnett at a rapid pace.

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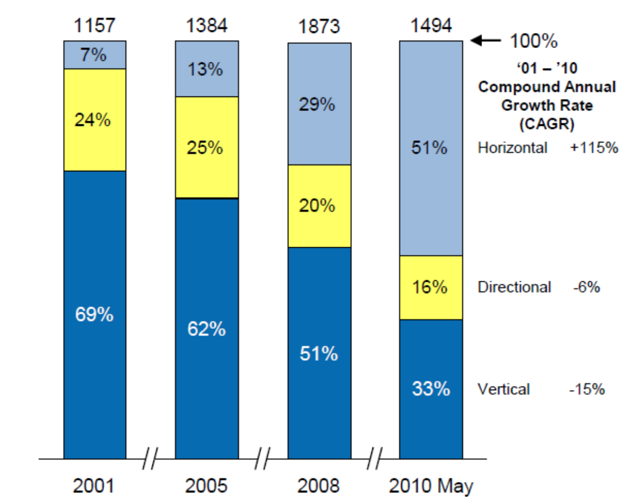
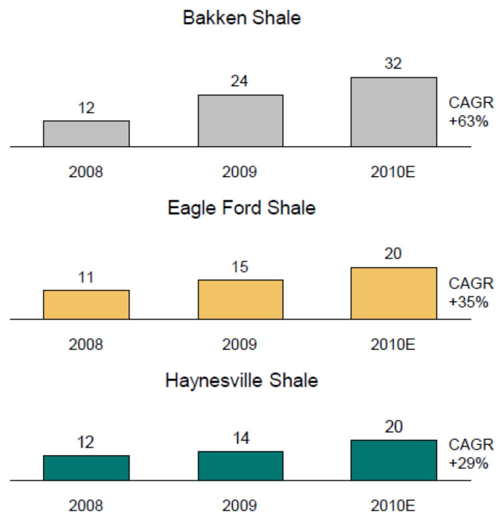
Unconventionals are Changing The Game

Rig Direction and Frac Stages

US Average Land Rig Count by Direction



Number of Frac Stages Per Well



- Production is increasingly moving towards horizontal wells with longer laterals to increase the surface area in a well
- Longer laterals are increasing the number of frac stages required and subsequently, the horsepower required

Source: Simmons and Company

7/8/11 Update:
US Land – 1854
Horizontal – 1073
% of total - 58

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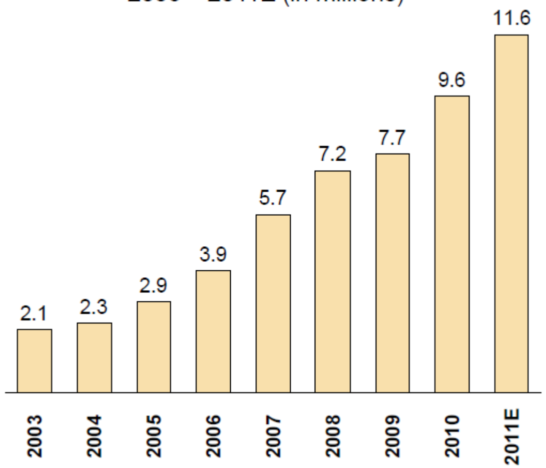
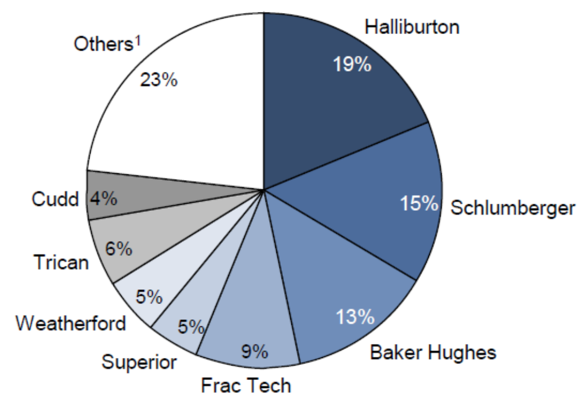
Unconventionals are Changing The Game

Oil Field Services Market

Estimated North American Pressure Pumping Horsepower
2003 – 2011E (in millions)



Representation of North American Pressure Pumping Horsepower
2011E



- Even with the 24% growth of horsepower between 2009 and 2010, there is still demand for additional pressure pumping equipment
- As the amount of horsepower increases, there will be additional service opportunities for United
- United Holdings serves a number of the large oil field service companies

1) Greater than 20 companies
Source: Spears & Associates, "Drilling: Market Forecast"

- ~ 450% increase in pumping capacity since 2003
- Still growing at ~ 20-25% per year

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The New Landscape - Unconventionals

- Almost exclusively **HW's**
- Almost all wells require **hydraulic fracturing**
- Long laterals (up to 10,000')
- More frac stages per lateral (>30)
  - Plug and perf capabilities extended
  - Packer and sleeve systems enhanced
- High rate (>100 bpm), large volume (> 100,000 bbls/well), high proppant tonnage (> 4,000,000 lbs/well) fracs
- 24 hour frac operations (30+ stages/24 hrs)
- "Factory" style multi-well pads and innovative frac sequencing
  - Zipper fracs
  - Simultaneous fracs
- **Result is significantly more data at a much faster pace**
- **Operators (and service providers) are overwhelmed**

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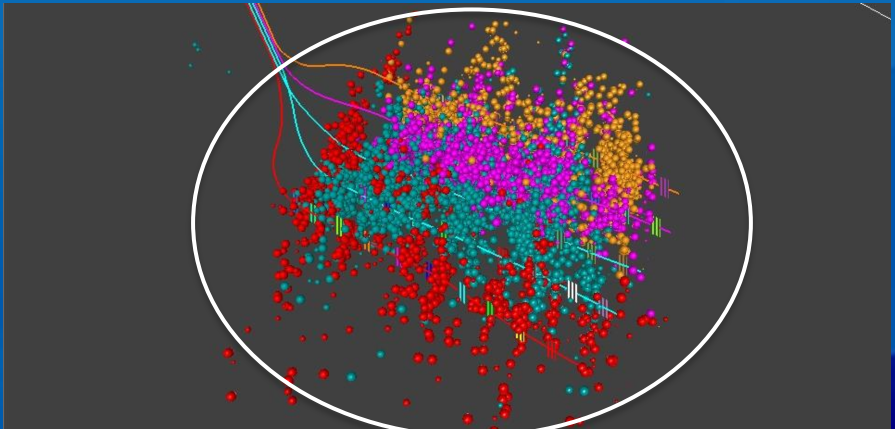
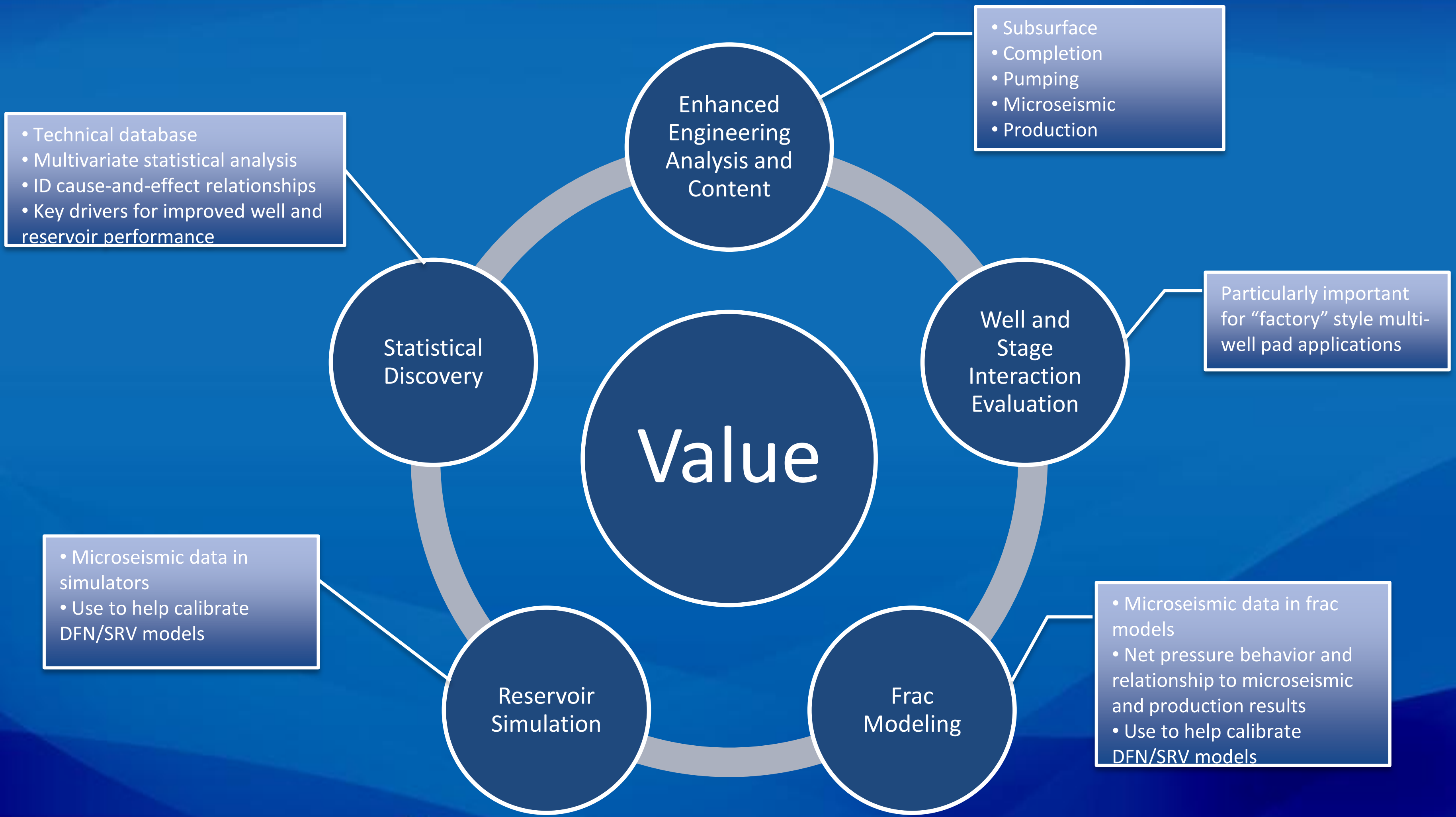
Microseismic Frac Mapping – Beyond the Dots

- Engineers are asking:
  - What Does it Mean?
  - How does it relate to production?
  - What needs to be changed?
- Determination of individual well fracture geometries , well orientation and well spacing requirements are no longer enough
- Must view and analyze as a "system"
- Engineers want an integrated solution:
  - Subsurface
    - Geophysics
    - Geology
    - Petrophysics
    - Geomechanics
  - Completion
  - Treatment
  - Microseismic
  - Production



View as System, not just individual wells

Value Addition Opportunity Model



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What's Ahead

- Continued R&D on event characterization to improve understanding of how the rock is breaking
- Improved understanding of "created" versus "effective" fracture geometry – "Where is the proppant?"
- Better understanding of how fracture geometry evolves during a treatment
  - Are we reactivating pre-existing fractures or creating new fractures or both?
  - Which is more prevalent?
  - How are stress changes that occur during fracture treatments driving and/or rerouting the fractures?
- Better understanding of the connectivity and flow properties of the hydraulic fracture network

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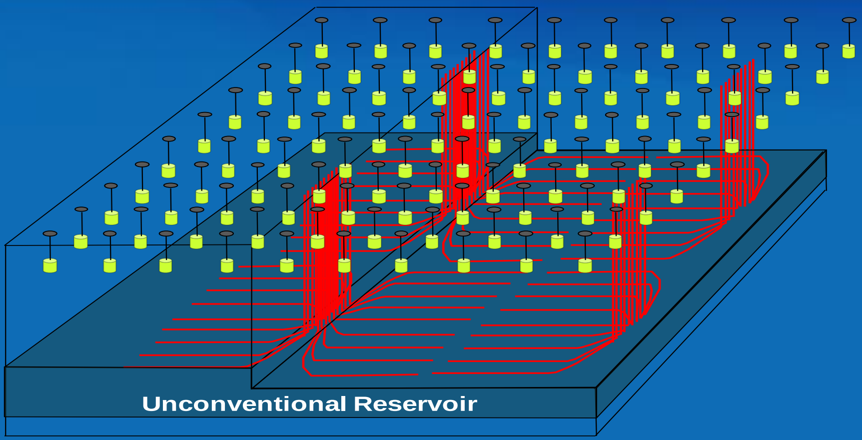
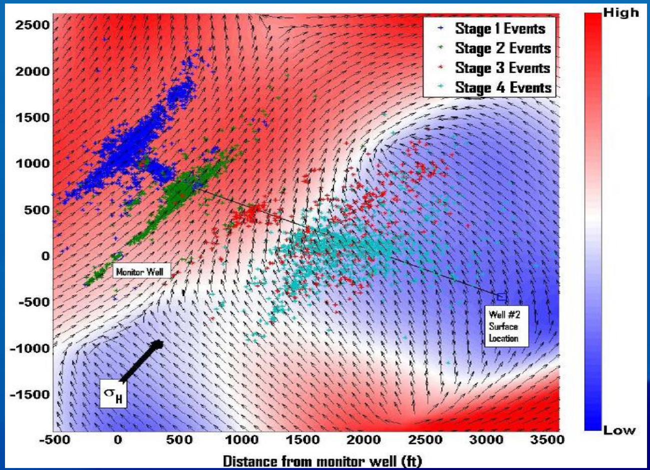
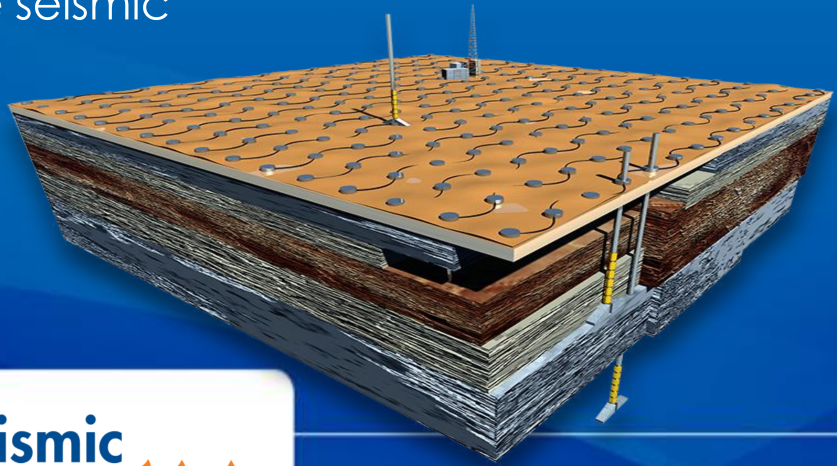
What's Ahead

- Reservoir Monitoring
  - Production, Haynesville
  - SAGD, Alberta
  - Water injection, Saudi Arabia
  - Compaction, North Sea
  - Production, North Sea
  - Cyclic Steam Injection, Alberta
  - CO_2 Injection, Wyoming
  - Gas Injection, Dubai
- Earthquake Monitoring
- Environmental Monitoring
- Integration of active and passive seismic







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Final Thoughts

"The wise man must remember that while he is a descendant of the past, he is a parent of the future." ~ Herbert Spencer

"You can't have one foot in yesterday or one foot in tomorrow; you have to keep both feet in today and that's how you get to tomorrow. " ~ John Wooden

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