Risk, Wells and Hydraulic Fracturing Monitoring

Public Presentation

Select Committee on the Risks and Benefits of Hydraulic Fracturing

Photograph by Damien Tremblay

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University of Alberta

February 1, 2014

My Background

- Professor of Geotechnical Engineering at University of Alberta (1997- ?)
- Prior to that, cofounded a reservoir surveillance company (…installed instrumentation for monitoring downhole pressures and temperatures)
- At the University of Alberta, established the Reservoir Geomechanics Research Group, working primarily in the area of unconventional resource geomechanics and the geological storage of CO_2
- IEA GHG Weyburn-Midale CO_2 Storage and Monitoring Research Project since its inception and worked in well integrity and risk assessment area
- Theme leader in the Canadian Centre for Clean Coal, Carbon and Mineral Processing
- A member of the scientific and engineering research committee for the Aquistore project in Saskatchewan
- A member of CO_2CARE, an EU funded program looking at storage project abandonment; and several other CCS initiatives.
- Served on the organizing committees of IEA Greenhouse Gas R&D Networks in Risk Assessment, Wellbore Integrity and Monitoring
- Chair of a Canadian Standards Association Technical Committee that developed CSA Z741-12, a standard for the geological storage of CO_2.
- Member of an expert panel for the Council of Canadian Academies study "*Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction assessment*".

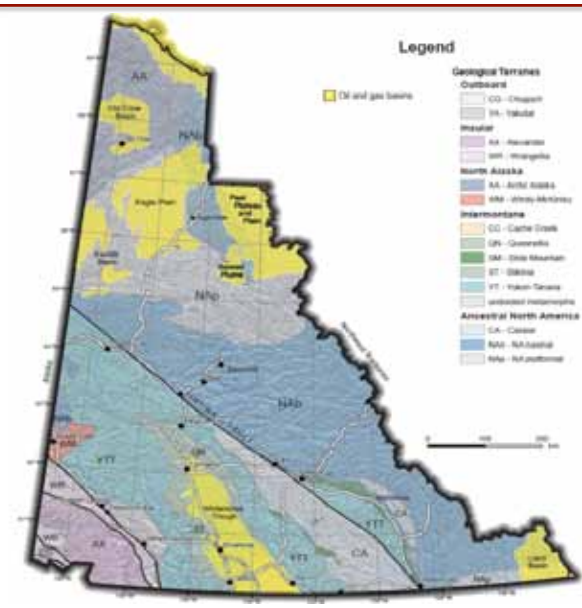
Harnessing Science & Technology to Understand the Environmental Impacts of Shale Gas Extraction

Council of Canadian Academies Report

- **Introduction**
- **SGD in Canadian Context**
- **SGD Technology and Well Integrity**
- **Water**
- **GHG's and Air Emissions**
- **Land and Seismic Impacts**
- **Human Health**
- **Monitoring and Research**
- **Management and Mitigation**
- **Conclusions**

http://www.scienceadvice.ca/en/assessments/in-progress/shale-gas.aspx

Yukon`s Shale Plays



Select Committee on the Risks and Benefits of Hydraulic Fracturing

Scoping Study of Unconventional Oil and Gas Potential, Yukon. Hayes and Archibald, 2012

Benefits of Shale Gas Development (..which requires hydraulic fracturing)

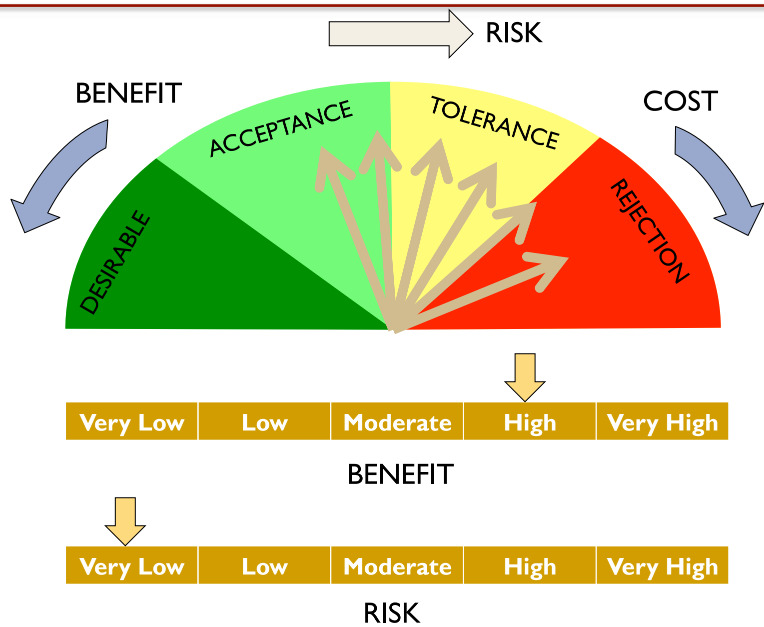
- Provide affordable energy to businesses and consumers in the industrial, residential and transportation sectors;
- Create direct and indirect employment and economic prosperity;
- Contribute to a (regions) energy security by lowering dependence on imported energy;
- Generate fewer greenhouse gas (GHG) emission than coal and oil;
- Provide a backup energy source to solar and wind renewables;
- ..and so on…

IRGC report, 2013

Risks of Shale Gas Development (..which requires hydraulic fracturing)

- Degradation of local air quality and water resources;
- Consumption of potentially scarce water supplies;
- Habitat fragmentation and ecosystem damage;
- Community stress and economic instability;
- Induced seismic events;
- Exacerbation of climate change by triggering more emissions of methane; and
- Slowing the rate of investment in more sustainable energy systems.

IRGC report, 2013



Reasons given by those not in favor of Shale Gas Development

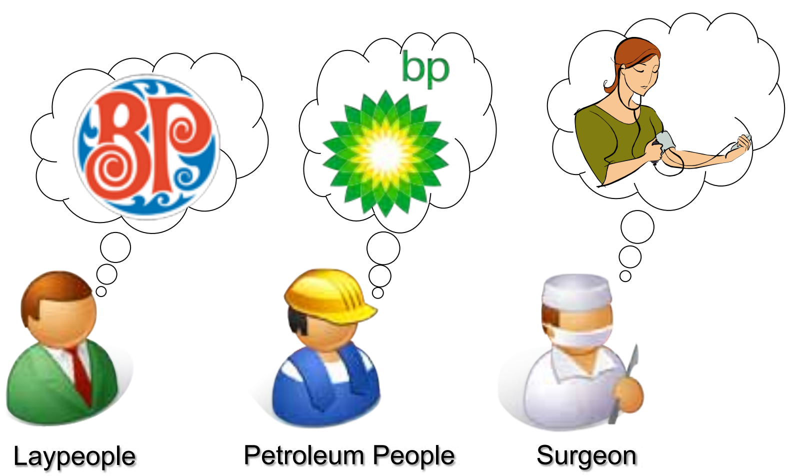
(Goldstein et al, Env Hlth Persp 120:483-486, 2012)
Washington, PA public meeting with Natural Gas Subcommittee of the Secretary of Energy Advisory Board, June, 2011 (N=59)

Reason	Percent (%)
Environmental Concerns	76.3
Negative Effects on Water	66.1
Negative Effects on Air	42.4
Chemicals in Water	30.5
General Health Concerns	61.0
Health Problem in Family member attributed to drilling	20.3
Personal legal rights have been infringed upon by companies	11.9
Concerns about safety of drilling operations	33.9
Concerns about lack of regulation of industry	42.4
Bias, conflict of interest, or lack of expertise in desired subject area by members of the committee	18.6
Export of domestic natural gas resources	10.2
Depreciation in property values	3.4

Risk Management Practices for Shale Gas Development

" risk can be managed, minimized, shared, transferred, or accepted. It cannot be ignored"

Risk Perception - What is BP?



Definitions?

- **Risk**
  - The chance of something happening that will have a (generally adverse) impact on HSE, cost, image, etc
  - It may be an event, action, or lack of action. It is measured in terms of consequences and likelihood/ probability.
  - Risk identification is the process of determining what can happen, why and how. Identifying risks requires looking at all possible sources of risk and the elements at risk.

- **Uncertainty**
  - lack of knowledge about specific variables, parameters, models, or other factors

Risk Matrix

Site Development and Drilling Preparation

After locating a site for shale gas development, the area must be excavated and prepared for drilling. Preparation activity also often includes leveling of the site.

Activity	Intermediate Impacts					
	Groundwater	Surface Water	Soil Quality	Air Quality	Habitat Disruption	Community Disruption
Clearing of land/construction of roads, well pads, pipelines, other infrastructure		Stormwater flows Invasive species	Stormwater flows	Conventional air pollutants and CO_2	Habitat fragmentation Invasive species	Industrial landscape Light pollution Noise pollution
On-road vehicle activity		Stormwater flows		Conventional air pollutants and CO_2	Other	Noise pollution Road congestion/accidents
Off-road vehicle activity		Stormwater flows		Conventional air pollutants and CO_2	Other	Noise pollution

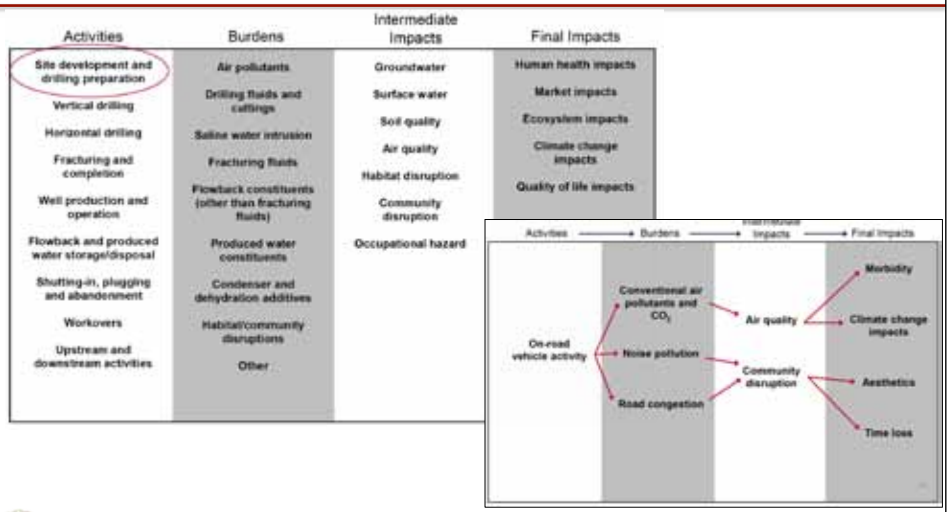
Drilling Activities

Drilling begins by boring a single well shaft vertically into the desired formation. One or more lateral wells are then drilled from the end of the vertical wellbore, angling to run horizontally through the shale formation.

Activity	Intermediate Impacts					
	Groundwater	Surface Water	Soil Quality	Air Quality	Habitat Disruption	Community Disruption
Drilling equipment operation at surface	Drilling fluids/cuttings	Drilling fluids/cuttings	Drilling fluids/cuttings	Conventional air pollutants and CO_2		Industrial landscape Light pollution Noise pollution
Drilling of vertical and lateral wellbore	Methane Drilling fluids/cuttings Intrusion of saline-formation water into fresh groundwater	Drilling fluids/cuttings		Methane		

A. Krupnick and S. Olmstead, Center for Energy Economics and Policy
Cumulative Risks of Shale Gas Development
National Research Council Workshop on Shale Gas Development Risks
May 30-31st 2013 - Washington, DC

Creating Risk Pathways



A. Krupnick and S. Olmstead, Center for Energy Economics and Policy
Cumulative Risks of Shale Gas Development
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Assessing the Risks

Risk Matrix

1. Expert survey of shale gas development risks
2. Statistical analysis:
   a) Effects of shale gas activity on surface water quality in Pennsylvania
   b) Analysis of chemical assays of flowback/produced water
3. State-by-state regulatory analysis
4. Citizen Survey
5. Cross cutting observations

5

A. Krupnick and S. Olmstead, Center for Energy Economics and Policy
Cumulative Risks of Shale Gas Development
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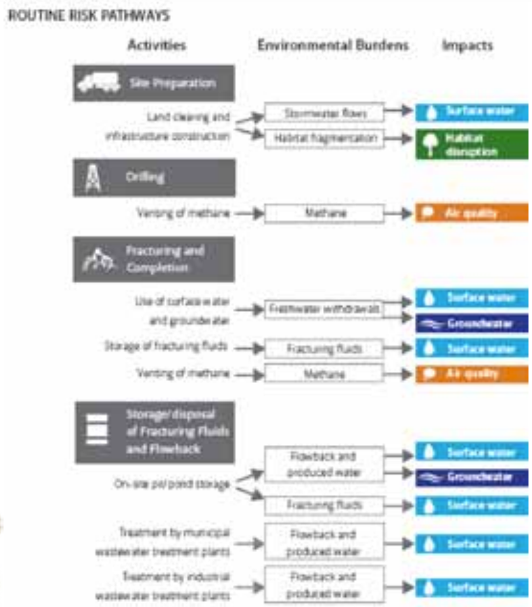
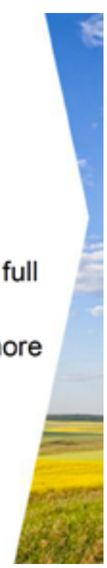
What is known about the risks?



Research, Field Data, etc.

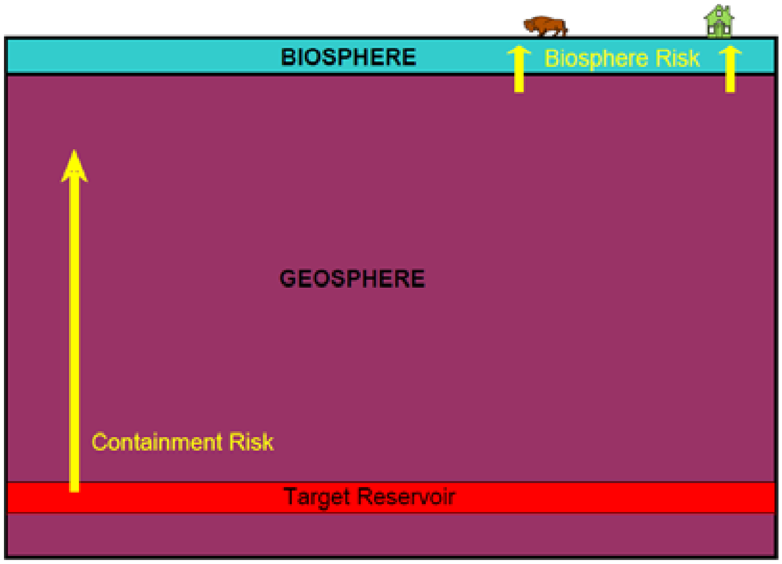
AER Draft Unconventional Regulatory Framework

- **Responding to the intensity, duration and scale of developing unconventional resources:**
  - Starts with existing regulations and processes
  - Organize risks by play, integrate surface and subsurface
  - Regulatory response proportional to risk
  - Recognize differences from exploration to piloting to full development
  - Expand regulatory focus from proximity impacts to more cumulative, play-based impacts
  - Support innovation and science
  - Increase early planning and collaboration amongst companies, expand information base, and enhance community engagement

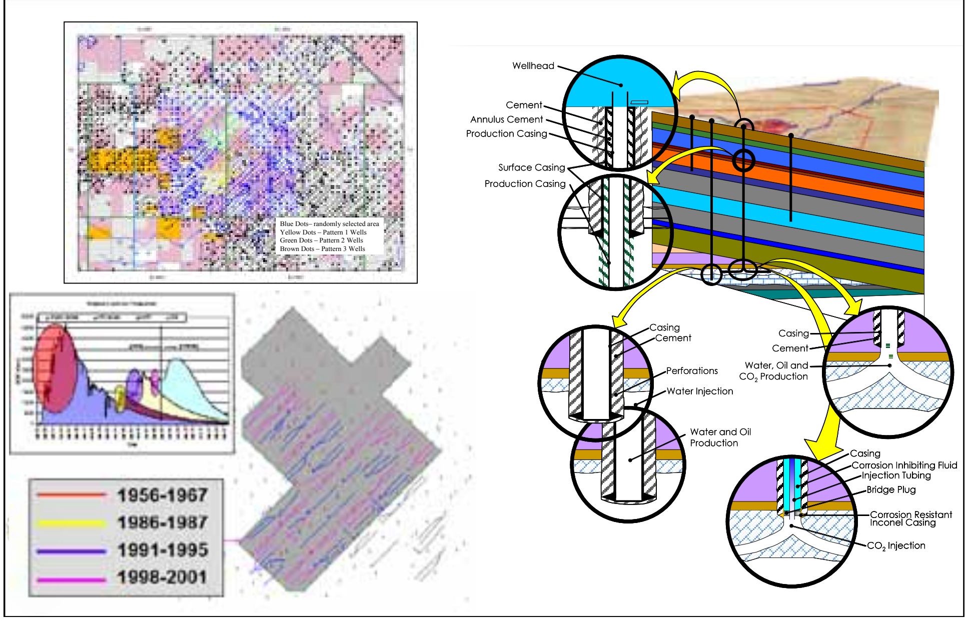


Alberta Energy Regulator

Approach for CO_2 Storage



Well Integrity within the Weyburn Project



Process: Geosphere & Biosphere Risk

Technical Inputs
- Wellbore integrity research
- Characterisation of reservoir characteristics & transport of CO_2
- Seismicity of area
- Characterisation of CO_2 reactions in reservoir
- Monitoring techniques & effectiveness

Geosphere Risk Assessment

Outputs
- CO_2 risk events (initiating event & pathway) & ranking
- Mass of CO_2 released if event occurs
- Likelihood of each event occurring & releasing CO_2

Stakeholder Engagement

Stakeholder Values

Building Capacity to Engage

Acceptability of Risks

Biosphere Risk Assessment

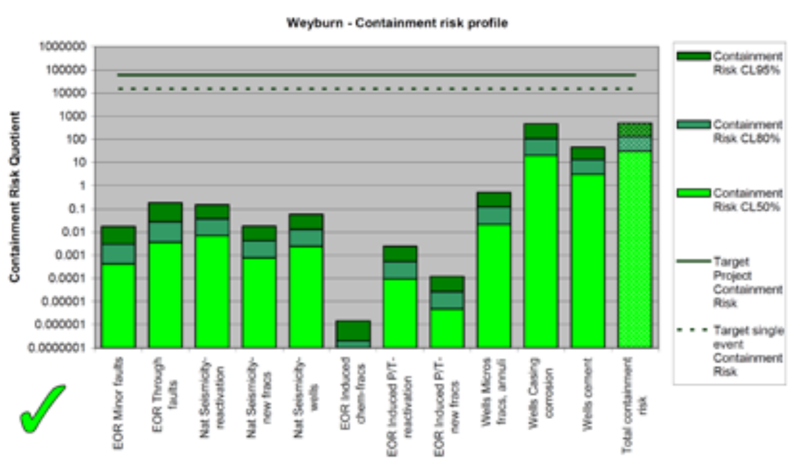
Other Technical Inputs
- Characterisation of aquifers
- Characterisation of surface water
- Characterisation of soils / sediments
- Behaviour of CO_2 in soils, sediments, groundwater, surface water
- Receptors in environment
- Toxicology (animal, plant, human)

Outputs
- Risks to biosphere assets (ranking & severity)

Mitigation Measures

Containment Risk Profile

The storage will retain most of the CO_2 injected ← Containment risk assessment

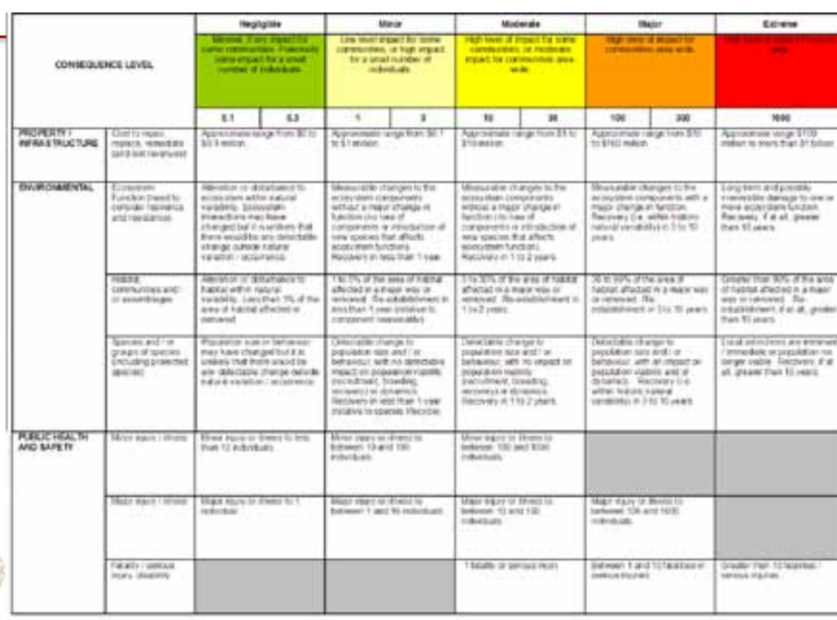


No further work would be required to demonstrate containment acceptability.

CO_2 flow rates from containment model and assumptions used to calculate rates

Containment Risk Event & Pathway	Flow rate from entire feature (g/d)	Feature width (m)	Feature length (m)	Area of feature (m2)	Flow rate (g/d/m2)
CO_2 migrates through a network of minor fractures extending to the biosphere	35	1,000	1,000	1,000,000	3.50×10^{-05}
CO_2 migrates to and through the Souris River fault	347	100	10,000	1,000,000	3.47×10^{-04}
Nat Seismicity causes reactivation of Souris River fault which then allows CO_2 migration	3466	100	10,000	1,000,000	3.47×10^{-03}
Nat Seismicity cases a network of new fractures which then allow CO_2 migration	347	1,000	1,000	1,000,000	3.47×10^{-04}
Nat Seismicity causes a loss of integrity of wells and allows CO_2 migration	0.347	1	1	1	0.347
EOR induced chemical variations lead to migration through fractures	8.66×10^{-03}	1,000	1,000	1,000,000	8.66×10^{-09}
EOR induced temperature and pressure variations lead to reactivation of fractures	0.866	100	10,000	1,000,000	8.66×10^{-07}
EOR induced temperature and pressure variations lead to new fractures	0.866	1,000	1,000	1,000,000	8.66×10^{-07}
Wells micro-fractures and micro-annuli in the well cement lead to migration of CO_2	0.347	1	1	1	0.347
Well casing corrosion leads to migration of CO_2	34.7	1	1	1	34.7
Cement channelling leads to migration of CO_2	3.47	1	1	1	3.47

Semi-quantitative Biosphere Consequences Table



Risk Assessment

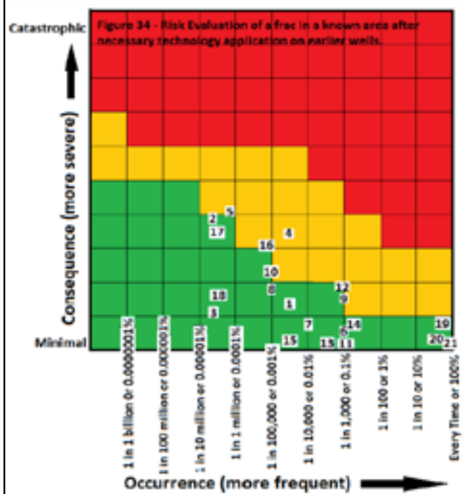


Image from King, G.E. (2012) SPE Paper No. 152596.

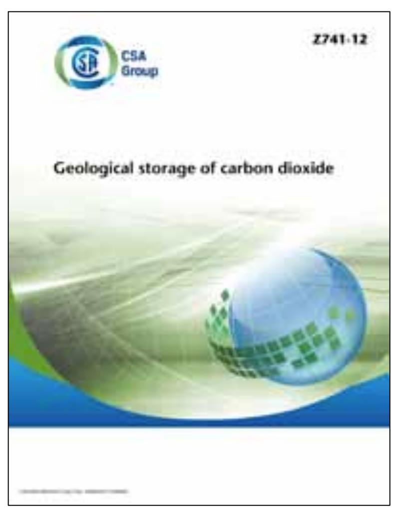
A recent SPE publication presents a assessment of publicly available data

- Risks can be effectively mitigated and most activities are generally lower risk
- A reasonable and prudent regulatory framework is required to foster responsible operations by all

1. *Spill of 130-bbl transport load*
2. *Spill of 500-gallons of liquid concentrated biocide or inhibitor*
3. *Spill of 500-lbs of dry frac chemical additives*
4. *Spill of 300-gallons diesel from diesel-fueled truck accident*
5. *Spill of 3500-gallons fuel from truck accident*
6. *Spill / leak from 500-bbl well site fluid storage tank*
7. *Spill of water treated for bacteria control*
8. *Spill of diesel while refueling pump trucks*
9. *Spill of 500-bbl stored flowback water from frac*
10. *Frac pressures ruptures surface casing at exact depth of fresh water sand*
11. *Frac fluid tubular cooling causes wellhead leak*
12. *Frac opens mud channel in cement in wells < 2000-ft deep*
13. *Frac opens mud channel in cement in wells > 2000-ft deep*
14. *Frac intersects another frac or well within a 1000-ft*
15. *Frac intersects an abandoned wellbore*
16. *Frac to surface through rock strata – shallow well < 2000-ft*
17. *Frac to surface through rock strata – deep well > 2000-ft*
18. *"Felt" earthquake from hydraulic fracturing of magnitude > 5*
19. *Frac changes output of natural seep at surface*
20. *Emissions*
21. *Normal frac operations without significant (reportable) spills, ruptures, leaks*

Standards for Storage

- Scope
- Reference publications
- Definitions
- Management systems
- Site screening, selection and characterization
- Risk management
- Well infrastructure development
- Monitoring and verification
- Closure



Risk Management and Monitoring

- The purpose of risk management is to ensure that the opportunities and risks involved in an activity are effectively managed and documented in an accurate, balanced, transparent, and traceable way.
- The purpose of monitoring and verification (M&V) is to address health, safety, and environmental risks and assess storage performance.
- Monitoring refers to measurement and surveillance activities necessary to provide an assurance of the integrity of CO_2 storage.
- Project operators shall develop and implement an M&V program suited to their operation and shall be designed to serve the following objectives:
  - (a) to protect health, safety, and the environment throughout the project life cycle by detecting early warning signs of significant irregularities or unexpected movement of CO_2 or formation fluid

Comments on

- **Shale**
- **Well Construction**
- **Microseismic Monitoring**

Gas Shale "Reservoir"

- **Properties: organic content, mineralogy, maturity, natural fractures, porosity, k…**
- **The gas in the shale is stored in:**
  - Natural fractures, fracture connected pore space
  - Adsorbed on mineral surfaces
  - Adsorbed on organic material
- **The reservoir is:**
  - Continuous and laterally extensive
  - Thick – usually > 20 m
- **Horizontal wells & fracturing are the "key"**

Key Reservoir Parameters

- Brittle Rock – **Helps maximize extent of induced fracture network**
  (Brittle Rock will Frac like Glass = better SRV)
- Stress Regime – **Relates to pattern orientation and well spacing**
- Over-pressure – **May require high strength Frac proppants**
- Local Lithology Variations
- Faults, Karsts, Water

  } **Relates to well productivity**
- Organic Content
- Micro-porosity

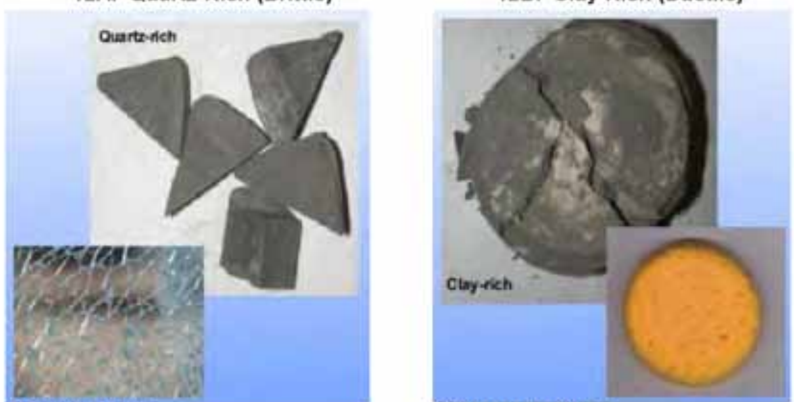
  } **Relates to gas in place** (Total Porosity increases at higher TOC; TOC decreases at higher R_o)
- Thermal Maturity (**R_o**) - **>Mature = Dry Gas <Mature = Wet Gas**

R. Kennedy (Baker Hughes) "Shale Gas Challenges / Technologies over the Asset Life Cycle"
U.S. – China Oil and Gas Industry Forum, Sept. 2010

Brittleness

High clastic content shales are brittle and shatter, providing multiple dentrict fracture swarms. High clay content shales are plastic and absorb energy, providing single-planar fracs.

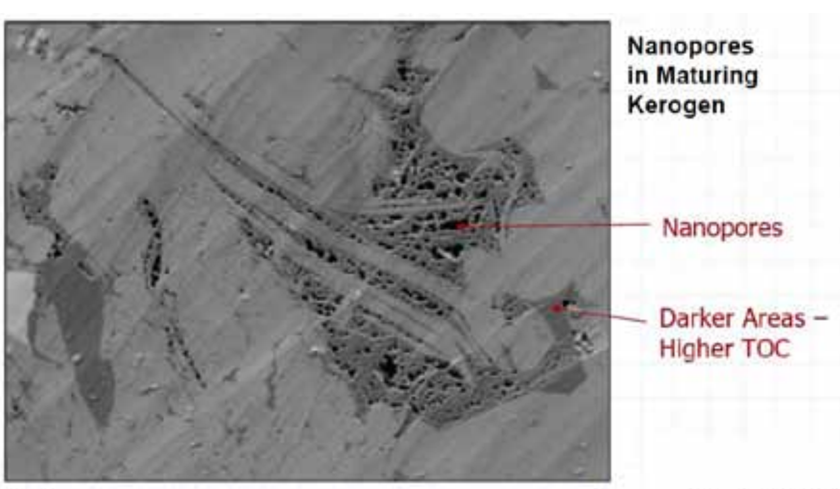
12A. Quartz-Rich (Brittle) **12B. Clay-Rich (Ductile)**



Barnett Shale **Cretaceous Shale**

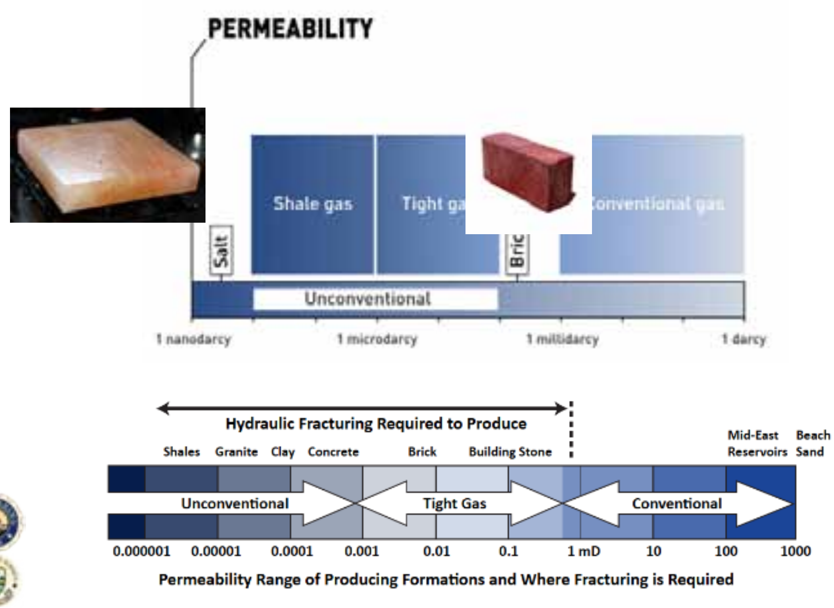
Source: CSUG, 2008

Pores and Organic Content



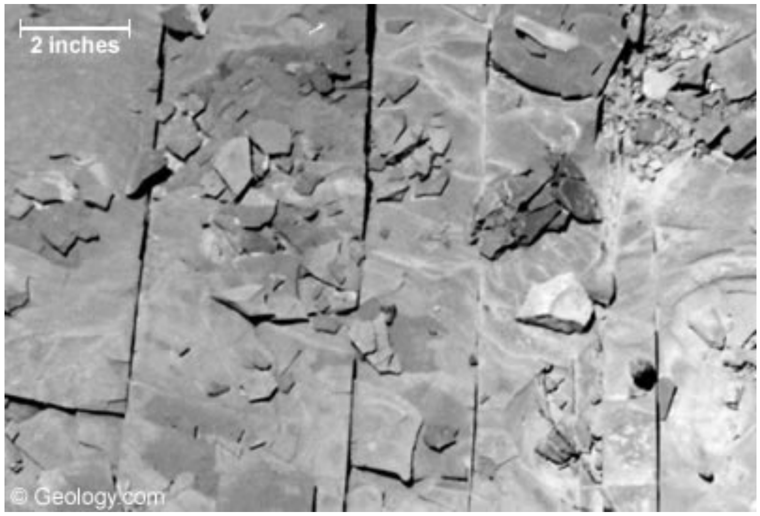
Source: Reed et al. Texas BEG

Permeability

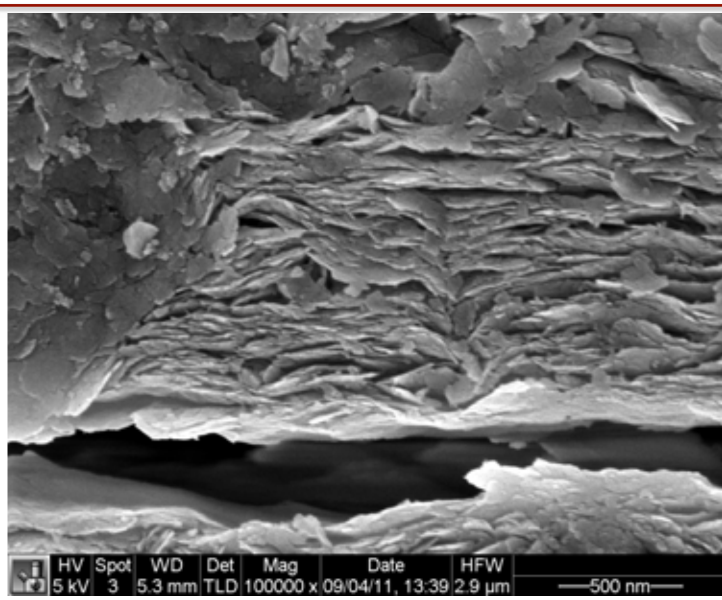


Natural Fractures in Shale

Devonian Fractured Shale

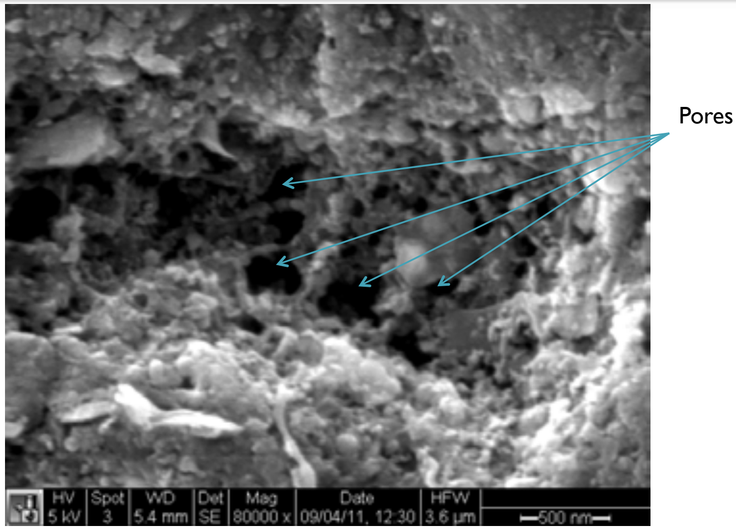


Eagleford Shale



Zoback, 2011, NEA Shale Gas Talk

Pore Structure

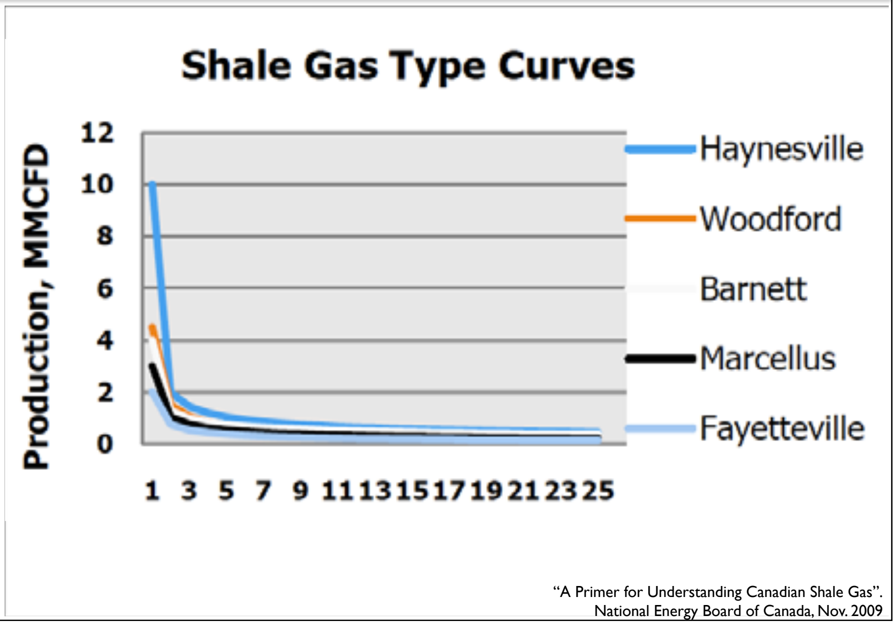


Zoback, 2011, NEA Shale Gas Talk

Properties

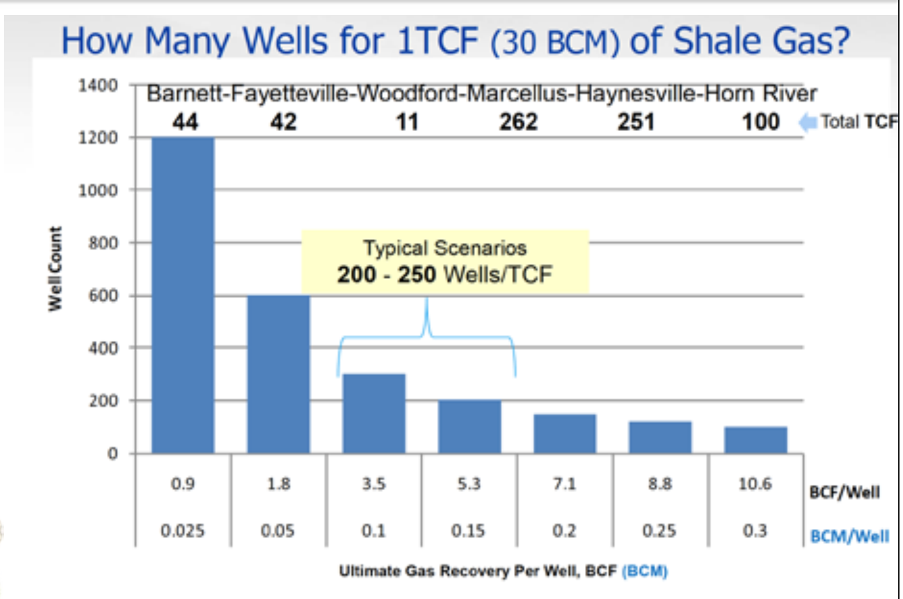
- Shale Gas plays are challenging mainly due to a very low permeability matrix.
- Economic flow rates can not be achieved using conventional technologies.
- Recovery factor is generally 5-30%.
- Production from a well is initially high, but declines rapidly in the first year until it reaches a plateau.
- A well is planned to produce for a few decades.

Gas Production from a well in Shale

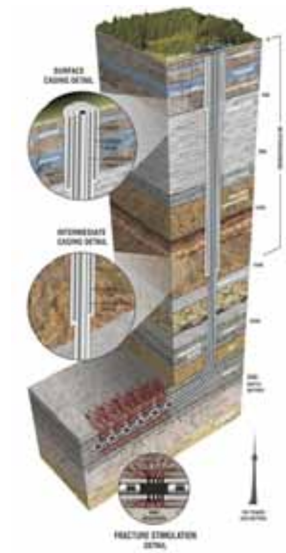


"A Primer for Understanding Canadian Shale Gas". National Energy Board of Canada, Nov. 2009

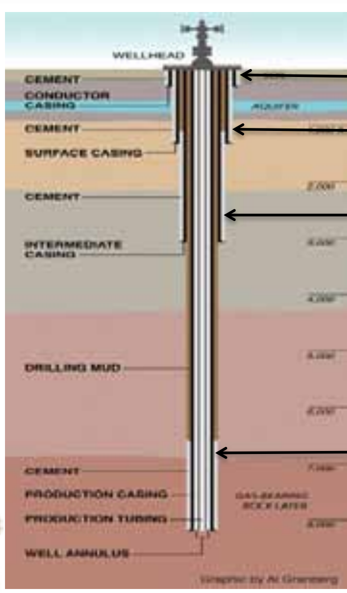
Shale Gas Development Requires a Large Number of Wells!



Well Construction



Casings

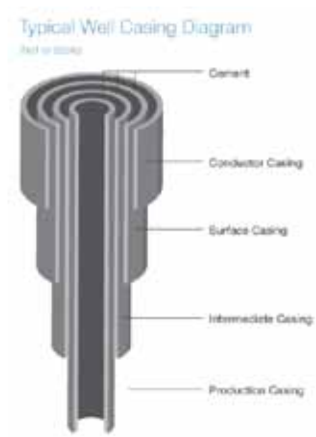


Conductor Casing

Surface Casing

Intermediate Casing

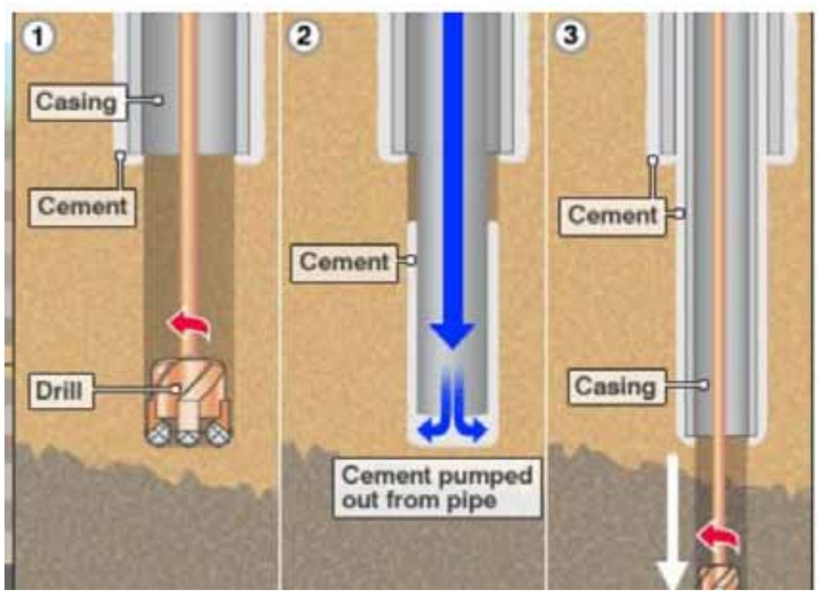
Production Casing



Cementing

- **The casings are set in place by cementing.**
- **The cements fills the space between the outer surface of the casing pipe and the surface of the wellbore.**
- **After each cementing the integrity of the cement job is tested and then the drilling continues.**

Cementing

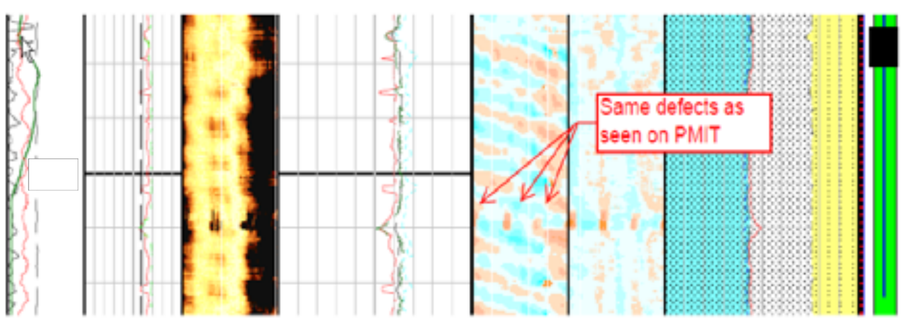


Well Evaluation Programs

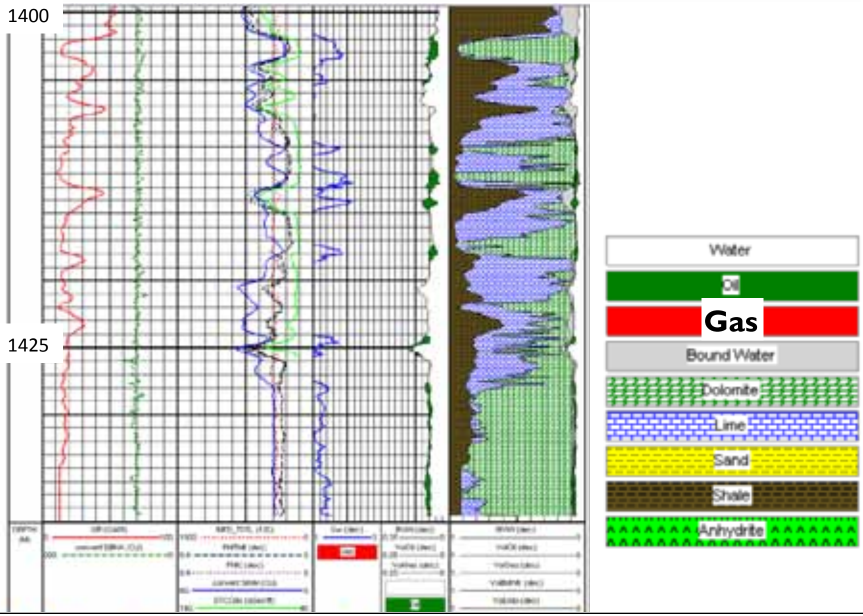
- Logging – Surface Hole (620m to surface, Completed)
  - GR / SP / Res / Density / Neutron
  - Sonic
- Coring
  - Interval 1: 3120 – 3138m
- DST (Drillstem Tests)
- Logging – TD section
  - GR / SP / Res / Density / Neutron (to surface shoe)
  - Sonic Compressional and Dipole Shear (to surface shoe)
  - NMR (interval of interest)
  - Formation Elemental Analysis (interval of interest)
  - Borehole Image Log
  - MDT – formation pressure & samples (TBD)
  - MDT – minifrac (TBD)
  - MDT – vertical interference test (TBD)
- Logging – Cased hole
  - Ultra sonic cement imager (entire production casing string)
- MMV Baselines
  - VSP (Zero-Offset)
  - RST

Isolation Scanner

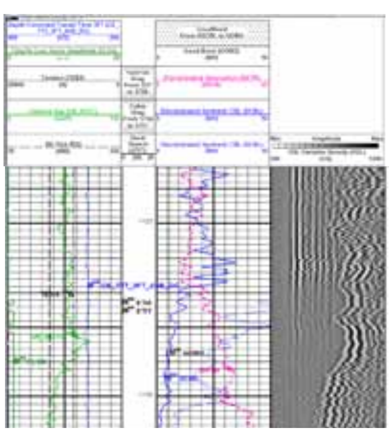
The PMIT log showed a clear defect at , and the USI picks this event up as well, but with less clarity due to eccentering. The same three evenly spaced defects can be observed

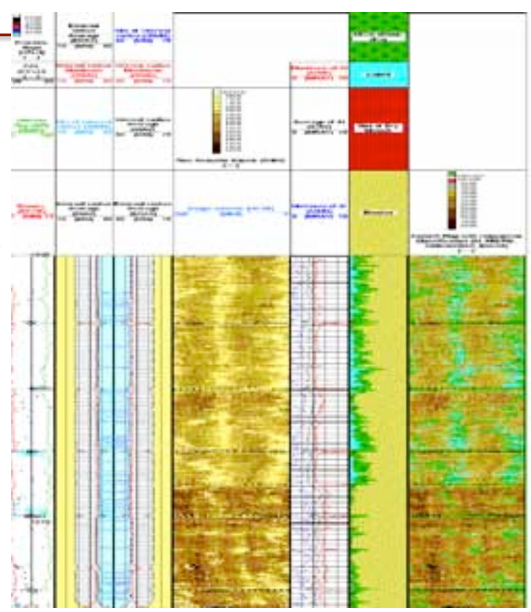


Behind Casing Assessment: RST Log



CBL and USIT





Well Integrity from NEB

4.4.4 Wellbore Integrity (wellbore, annulus, inter-wellbore)
4.4.5 Well Control System
4.4.6 Relief Well Capability
4.5 Well Completion and Hydraulic Fracturing Operations
4.5.1 Well Completion Operation
4.5.2 Hydraulic Fracturing Design
4.5.3 Hydraulic Fracture Operations
4.5.4 Formation Flow Tests
4.5.5 Well Suspension and Abandonment

FILING REQUIREMENTS FOR ONSHORE DRILLING OPERATIONS INVOLVING HYDRAULIC FRACTURING
September 2013

4.4.4 Wellbore Integrity (wellbore, annulus, inter-wellbore)

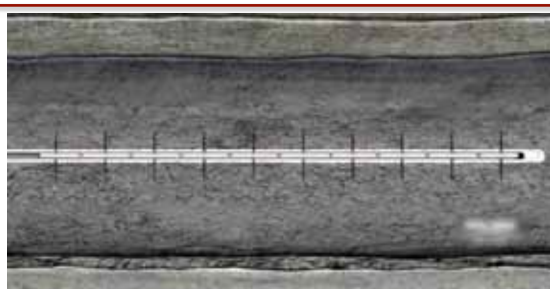
Goal

The applicant provides enough detail to demonstrate that:

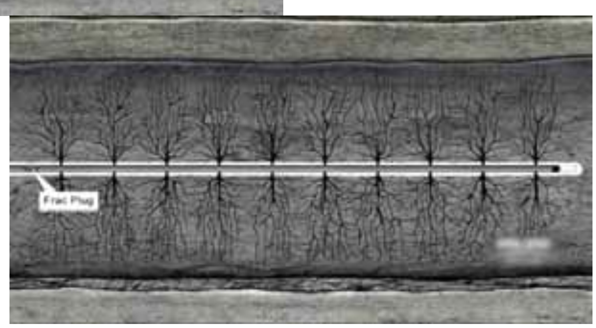
- at least two independent and tested physical well barriers are in place during each phase of well operations;
- well barriers ensure well integrity at all times during the well life cycle, and under all load conditions including completion and hydraulic fracturing operations; and
- if the well control is lost or if safety, environmental protection or the conservation of resources is threatened, the applicant will take any action necessary to rectify the situation without delay, despite any condition to the contrary in the well approval.

5. Demonstrate that the wellbore integrity is considered in the hydraulic fracturing design.

Perforation followed by Hydraulic Fracturing



After Perforation

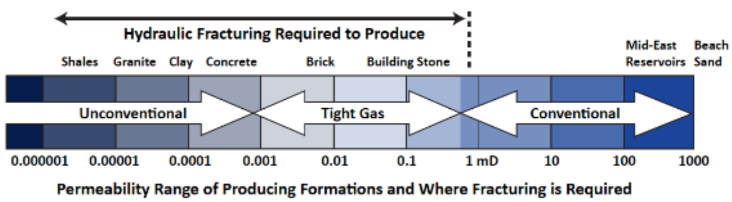


After Fracking

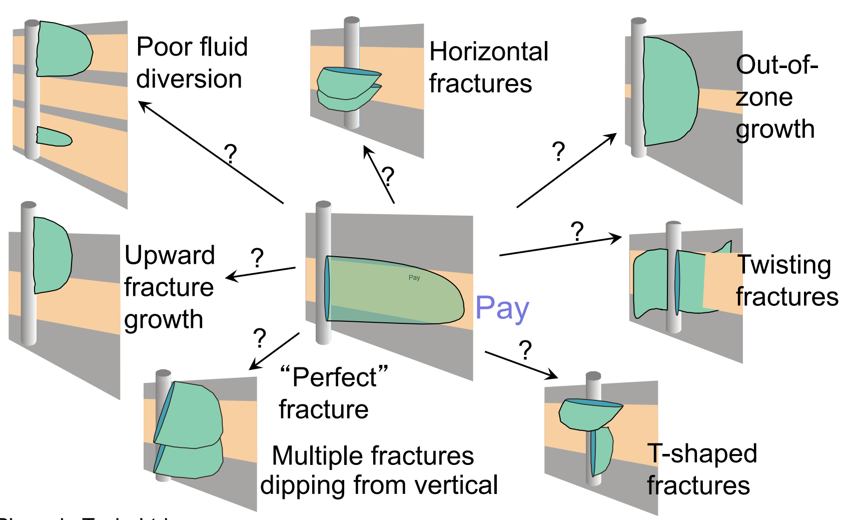
www.charlestayloradj.com

Hydraulic Fracturing Benefits

- **Fracturing increases the surface area**
  - Accelerates diffusion processes such as gas coming out of shale toward low pressure wells
- **Fracturing increases the contacted volume**
  - A greater volume of shale is "connected" to well
- **Permeability is increased by the fractures**
- **Fracturing can link up vertically separated zones to produce from one well**

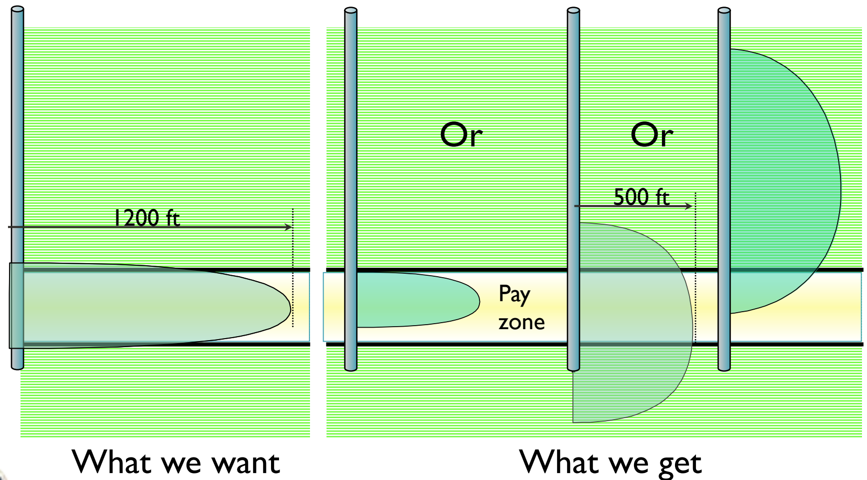


Fracture Growth is Complex!



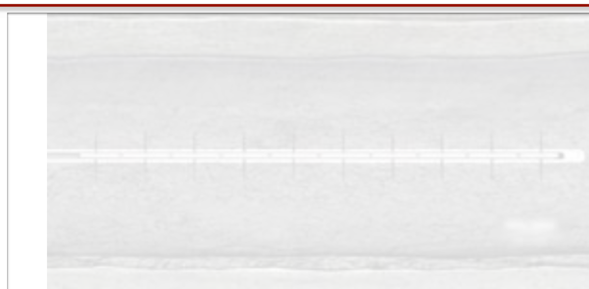
Pinnacle Tech. Ltd.

Fracture Growth Complications

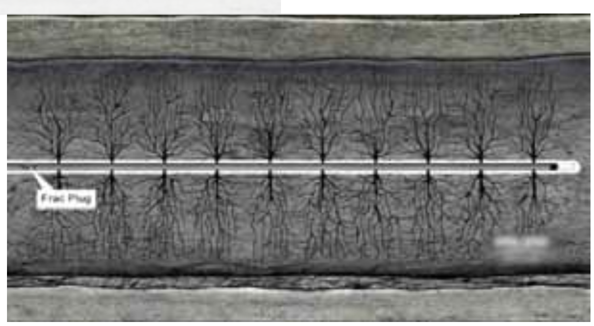


MBD Consulting Inc.

Perforation followed by Hydraulic Fracturing



After Perforation



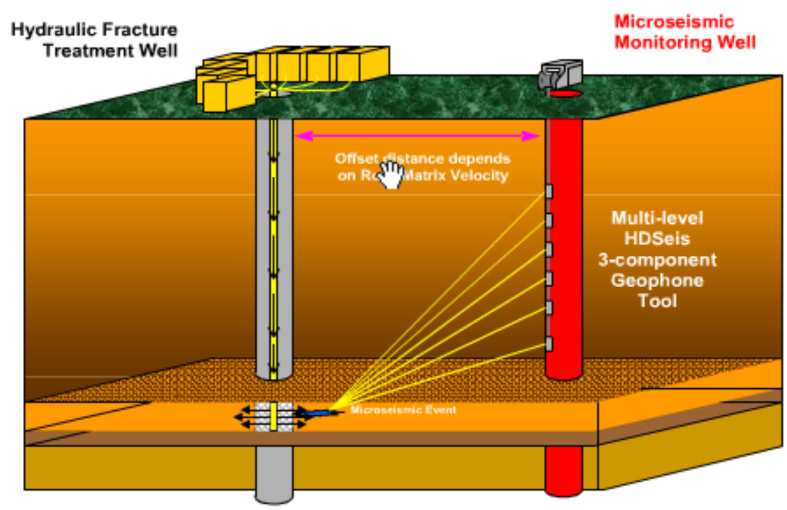
After Hydraulic Fracture Stimulation Program

www.charlestayloradj.com

HF Monitoring Methods

- **Precision real-time tilt monitoring (<3000m)**
  - Surface and subsurface deformation measurements during HF
- **Microseismic monitoring using geophones at depth relatively near the fracture site**
  - Concept of the stimulated zone which can be far larger than the propped zone
- **Pressure-time response in the injection well**
- **Impedance tests in a propped fracture**
- **Borehole geophysical logging (T, tracers)**

Microseismic HF Monitoring Concept

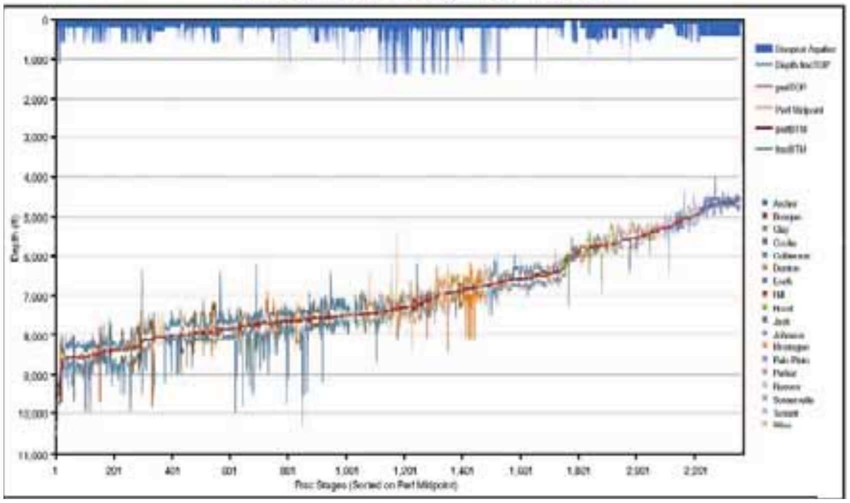


Microseismic Hydraulic Fracture Monitoring Technique

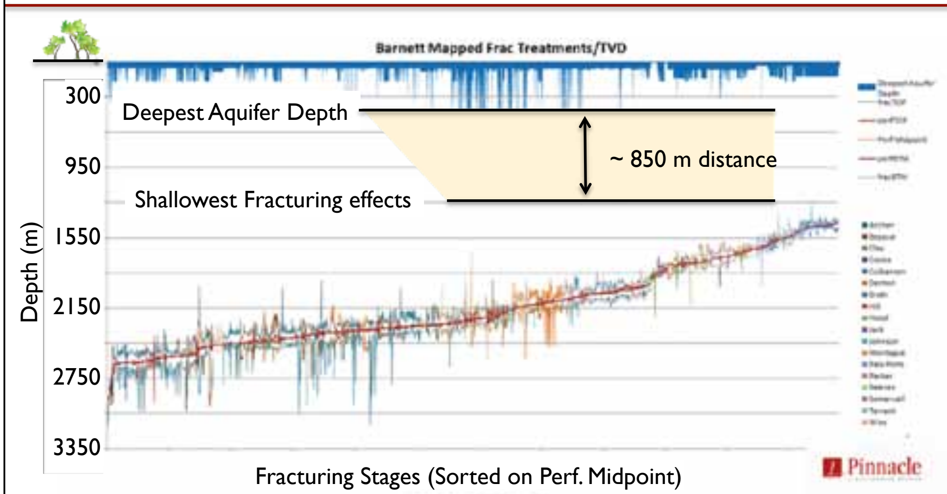
GeoSpace Technologies

Microseismic Monitoring

- **Monitoring of upper and lower limits of fracture height growth relative to the position of fresh water**



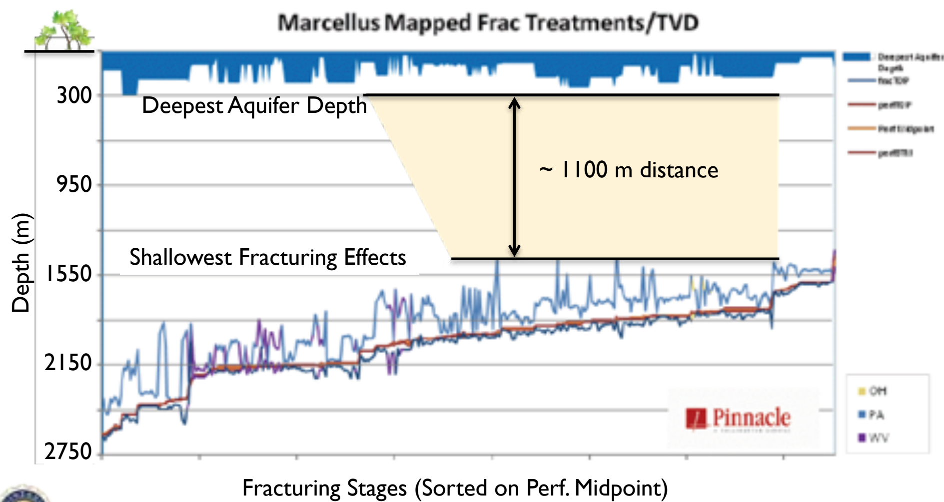
Subsurface Fluid Effects (Barnett Shale)



Fisher (2010)

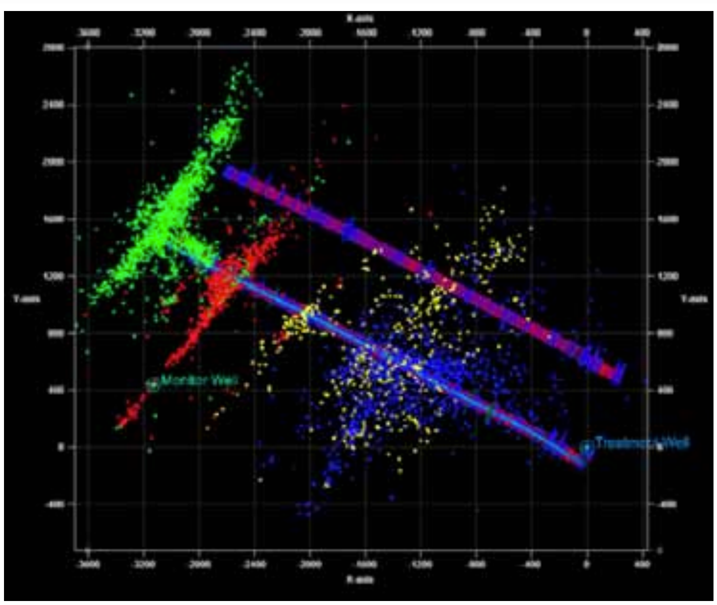
http://nwis.waterdata.usgs.gov/nwis/inventory

Subsurface Fluid Effects (Marcellus Shale)



Fisher (2010) http://nwis.waterdata.usgs.gov/nwis/inventory

Four Stage Hydraulic Fracture Stimulation in the Barnett Shale



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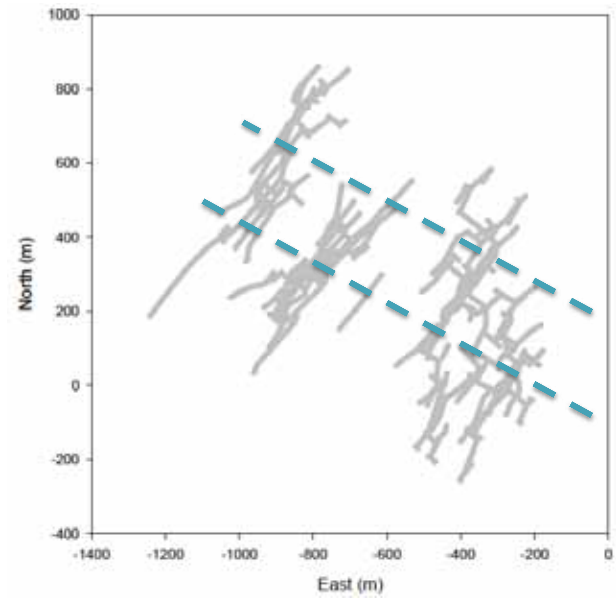
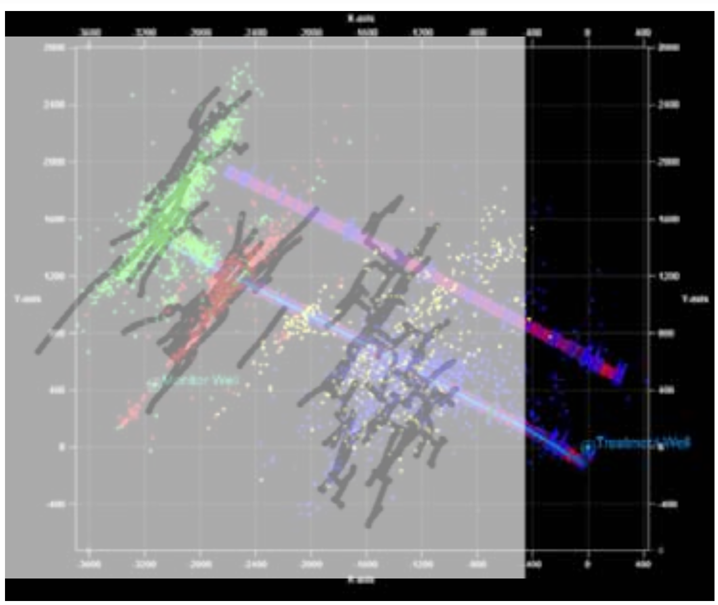
Fracture Network Segments Approximating the Extent of the Microseismicity



Four Stage Hydraulic Fracture Stimulation in the Barnett Shale



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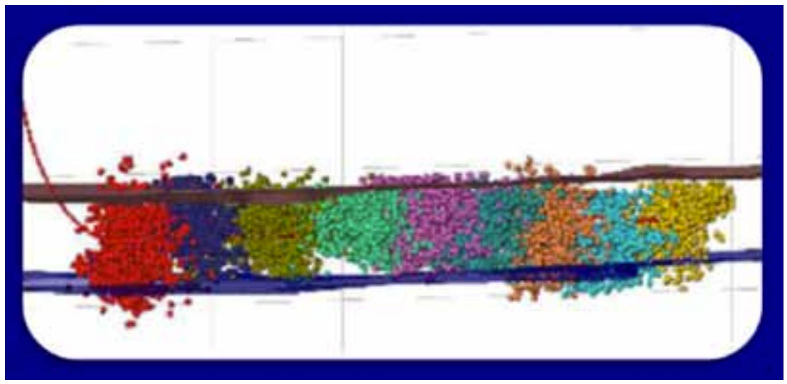
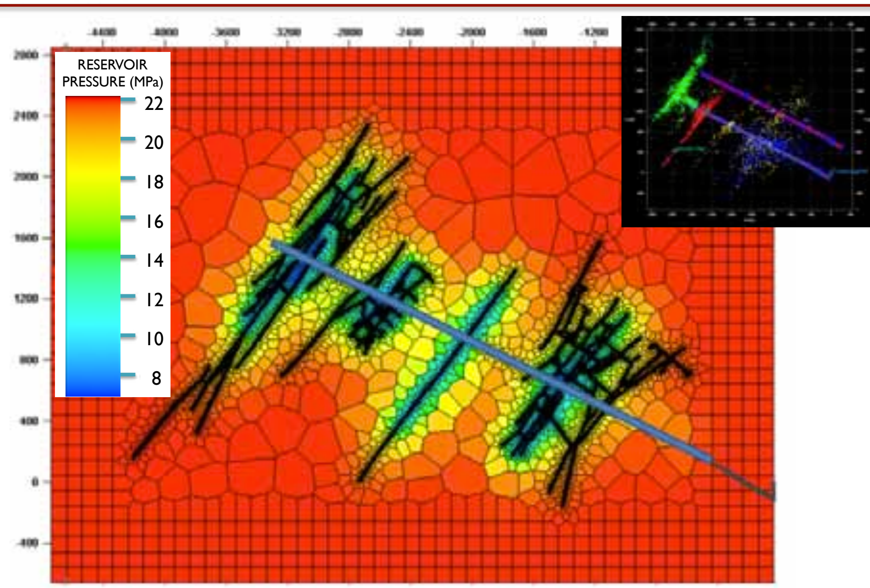
Depth Containment



SPE Distinguished Lecture Series: What Have We Learned About Fracturing Shales After 12 Years Of Microseismic Mapping?
Shawn Maxwell - Schlumberger

Reservoir Pressure Simulated after 20 Years of Production



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Risk, Wells and Hydraulic Fracturing Monitoring

Public Presentation

Select Committee on the Risks and Benefits of Hydraulic Fracturing

Photograph by Damien Tremblay

Rick Chalaturnyk, PhD, PEng
Professor, Geotechnical Engineering
University of Alberta

February 1, 2014