SHALE
HYDRAULIC FRACTURING

DRILLING, CASING AND CEMENTING CHALLENGES & TECHNOLOGIES

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Company:	Atlantic Council
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Place:	Bucharest

SHALE DEVELOPMENT - SUMMARY

- All shale reservoirs are NOT the same
- Shales must be fractured to produce commercially
- Hydraulic fracturing creates an artificial fractured reservoir (**S**timulated **R**eservoir **V**olume)
- Enabling technologies:
  1. Multistage hydraulic fracturing
  2. Horizontal wells
- Hydraulic fracturing effectiveness determines:
  1. Production rates
  2. Drainage area
  3. Recovery

SHALE DEVELOPMENT - ISSUES

PROBLEMS:

UNCON's are expensive to develop:

- Minimise drilling costs
- Optimise completion & fracturing designs
- Minimise environmental impacts

SOLUTIONS:

- Completion design and drilling practices
- Hydraulic fracturing operations
- Environmental developments

PRESENT RISK

Hydraulic Fracturing Risk:

- Fluid Contamination: chemical additives and known carcinogens
- Formation Fluids: Heavy metals, NORM (naturally occurring radioactive materials) and toxic minerals.
- Blowouts/uncontrolled release of hydrocarbons
- Surface spills and contamination

Risk Management Considerations:

Mitigation is by the use and application of best practices including standards for:

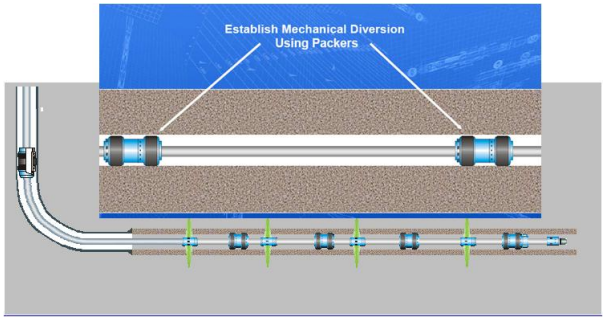
1. **Drilling and completion design**
2. **Cementing**
3. **Well integrity maintenance**
4. **Pre- and Post-drill testing**
5. **On-going well integrity monitoring and audits**
6. Site preparation and isolation
7. Handling of stimulation fluid and wastewaters

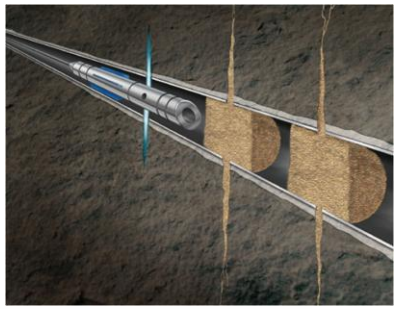
FRAC DESIGN OVERVIEW

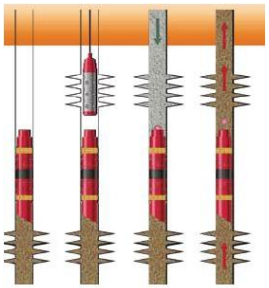
Clearly define the frac completion objectives **FIRST:**

1. **Vertical/Horizontal well (HW) and Completion Type**
2. **Frac Design:**
    1. **Frac Fluid**: What will be used and why?
    2. **Proppant**: Will the proppant retain strength and conductivity over the long term?
    3. **Rates**: High friction less net pressure
3. **Flow-Back/Clean-up**
4. **Well Spacing**

DESIGN – COMPLETIONS







COMPLETION:

- Open Hole or Cased/Cemented Hole
- More stages & smaller treatments, or less Stages & Larger Treatments?
- Multi-Stage Completion Isolation Techniques
- Interventions
- Production techniques
- Maximum lateral length that can be placed into the formation and effectively cleaned-up?

DEVELOPMENT – FRAC DIAGNOSTICS

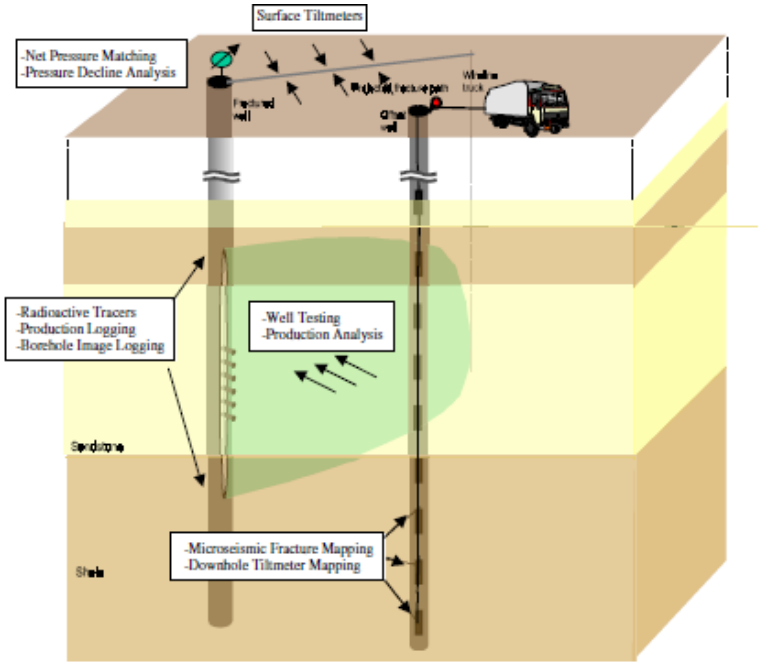


Figure 1 – Fracture Diagnostic Techiques

Table 1 – Capabilities & Limitation of Fracture Diagnostics

Techniques	Azimuth	Height	Length	Asymmetry	Width	Dip	Range
Microseismic	●	●	●	○		○	Far Field
Tiltmeters (downhole)	○	●	●	○	○		Far Field
Tiltmeters (surface)	●	○	○	○		●	Far Field
RA Tracer	○	○		↑	○		Near well
Temp Logs		○	*direct diagnostics*				Near well
Frac Models		○	○		○		Far Field
Well Testing			○		○		Far Field
Production Analysis			○	↑ *indirect diagnostics*	○		Far Field

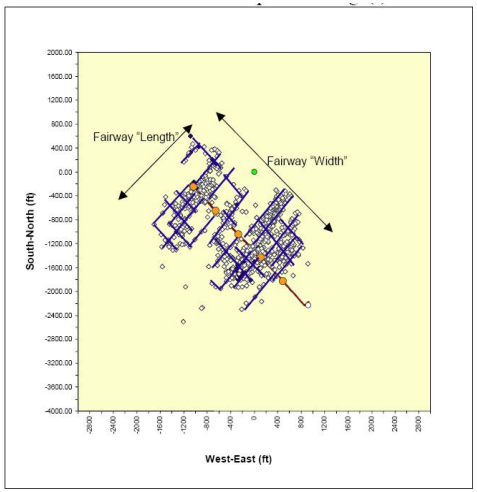
● Can determine
○ May determine

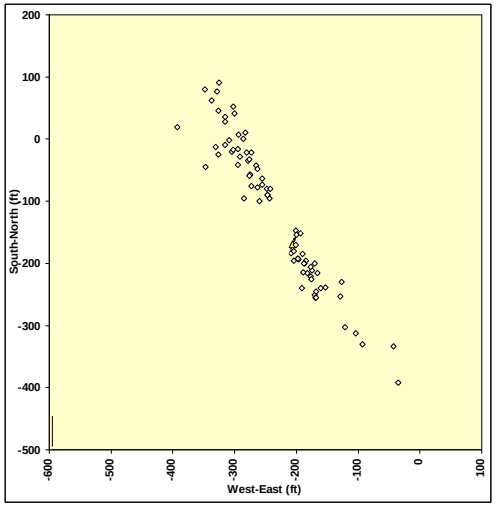
(SPE 64434, Cipolla and Wright, 2000)

Frac diagnostics should be considered in an holistic approach

The recommendation depends on the shale and what is required?

DEVELOPMENT – FRAC DESIGN



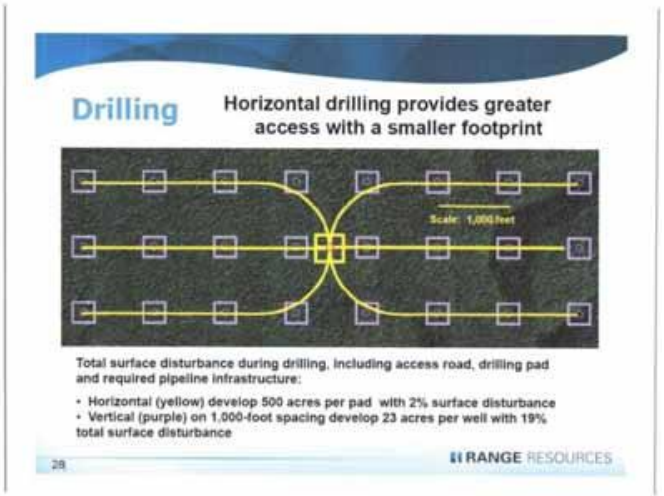


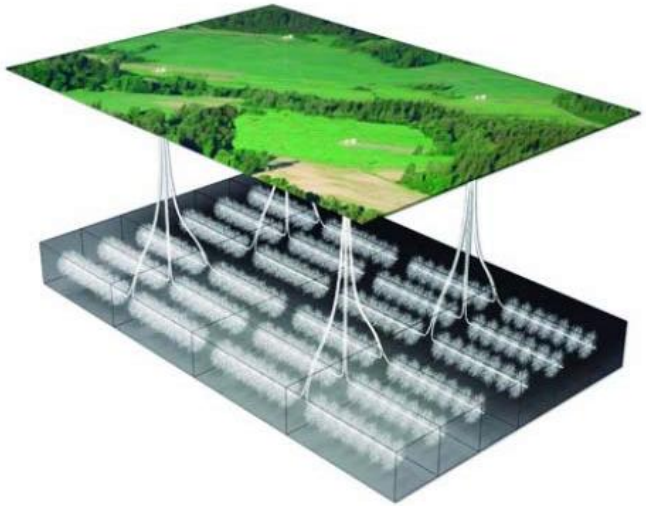
(SPE 90051, Fisher et al, 2004)

Single planar frac
- Limited surface area
- Flow through a small channel

Complex (shear) fracture network
- Large surface area exposed
- May not connect and drain entire network (load recovery experience)

DEVELOPMENT – SPACING





(Source 3Legs factsheet)

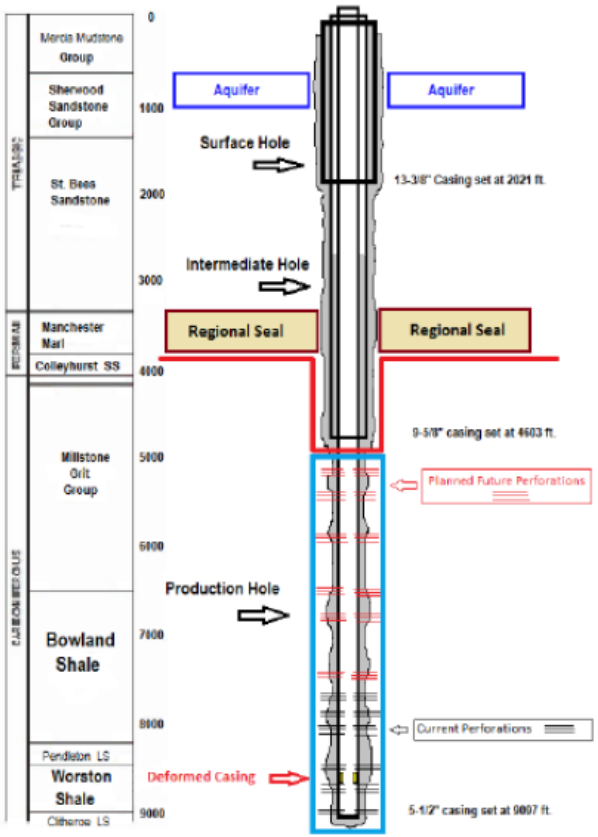
Centralised pads:

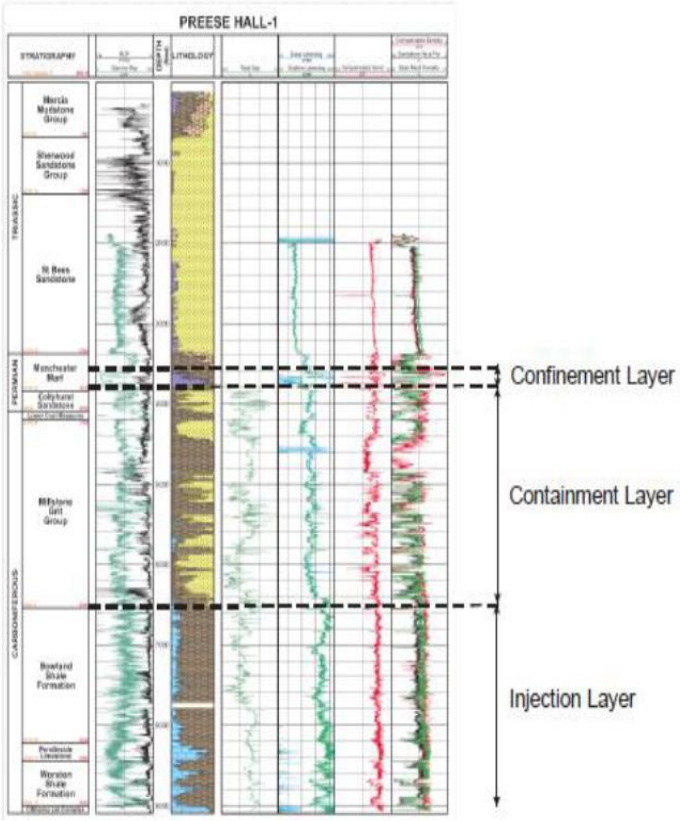
- 10+ wells from a single pad
- Shared drilling facilities
- Gas processing prior to export
- Minimised environmental impact
- Centralised controlled fluid processing

Environmental and operational optimisation by centralised dewatering

- Recycle processed water
- Centralised disposal point where suspended solids are removed.

MITIGATING RISK – LITHOLOGY



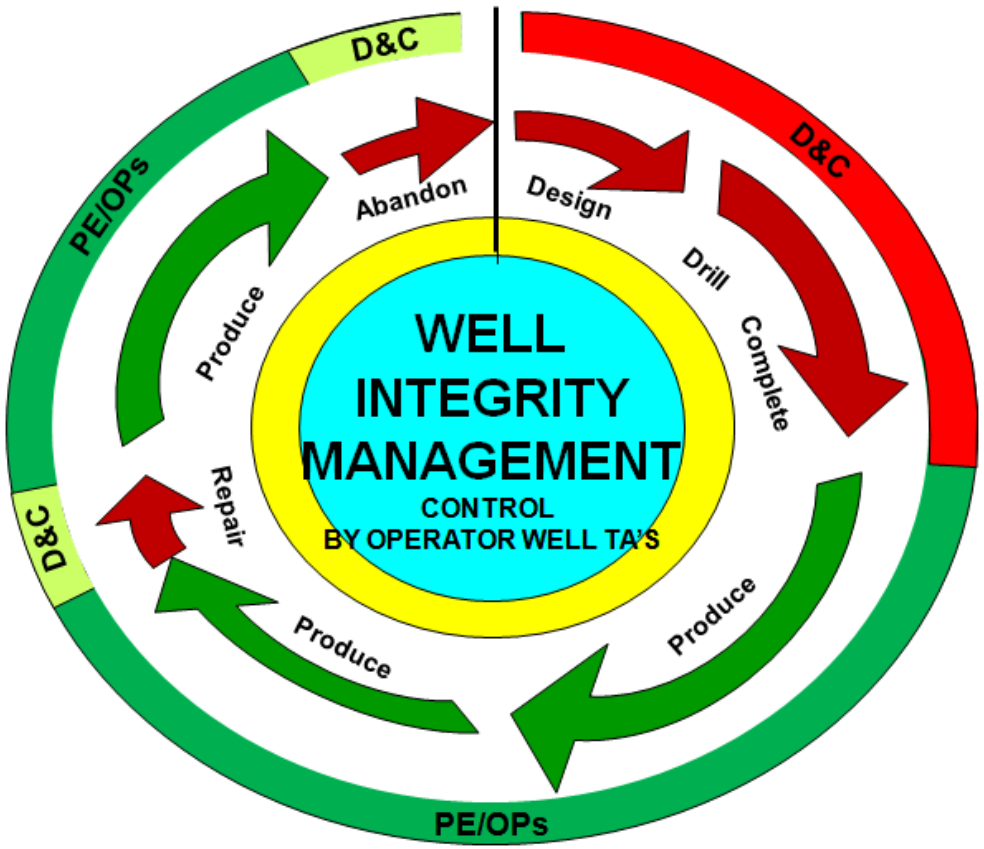


UK lithology is beneficial to mitigate containment issues:

1. Containment by 'Composite Layering'
2. Confinement by a regional seal

(Source de Pater and Baisch Cuadrilla Synthesis Report)

MITIGATING RISK – WELL INTEGRITY



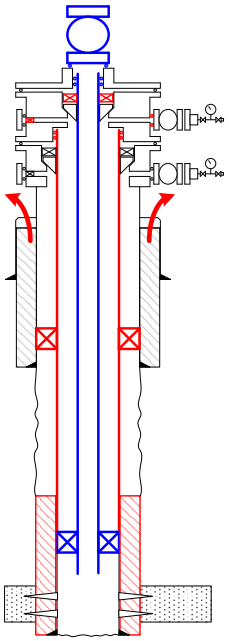
(Adapted from J ANDERS SPE Presentation)

Well integrity should cover the lifetime of the well:

1. Design phase
2. Construction phase
3. Production phase: Operation and Maintenance
4. Abandonment phase

Technical Authority (TA) roles and handover?

MITIGATING RISK – WI STANDARDS



API Standards

API 51R – Environmental Protection for Onshore Oil and Gas Production Operation and Leases. July 2005
API 65 - Isolating Potential Flow Zones During Well Construction (Dec 2010)
API Guidance Documents for Hydraulic Fracturing
API HF1 - Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines (Oct 2009)
API HF2 – Water Management Associated with Hydraulic Fracturing (June 2010)
API HF3 – Practices for Mitigating Surface Impacts Associated with Hydraulic Fracturing (Jan 2010)

(Source NORSOK and API)

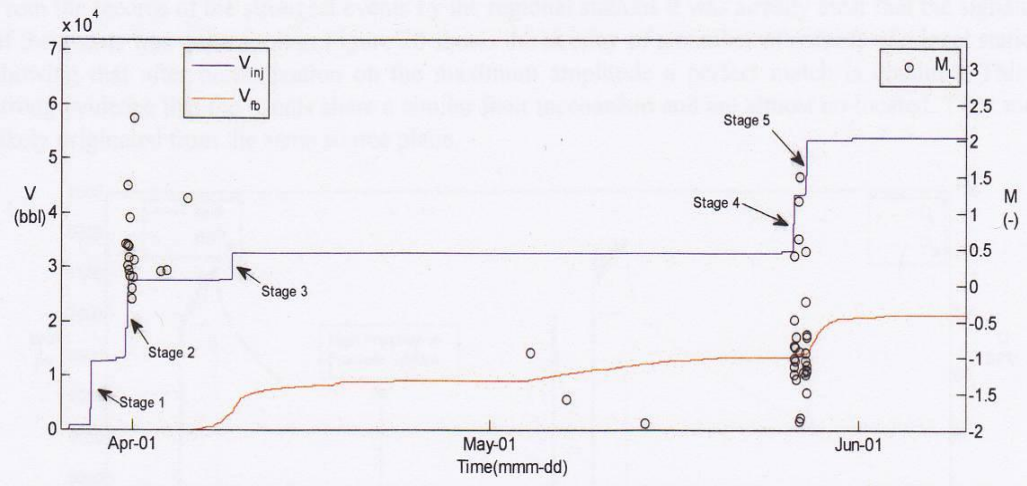
Audits and certifications are necessary for controls:

1. Well examiner involvement
2. Independent frac operations audits and certification, by specialists
3. Well integrity checks and audits

Existing construction standards (API/NORSOK/ISO) and guidelines

1. No need for additional regulations.
2. Implementation and applications needs to be monitored?
   - Regular audit by independent frac experts

INDUCED SEISMICITY – UK OVERVIEW



Stage	Description	Date	Perforations					Slickwater Volume			Proppant	
			Depth			Length	Number					
			Top	Bottom								
			ft MD_{RKB}	ft MD_{RKB}	ft TVD_{SS}	ft		Gallons US	m^3	bbls US	lbm	mton
1	DFIT	26 March 2011	8,841	8,850		9	27	34,314	130	817		
	Job	28 March 2011	8,841	8,949	8,730	36	108	485,856	1,839	11,568	226,240	101
2	DFIT	30 March 2011	8,700	8,759	8,583	27	81	24,780	94	590		
	Job	31 March 2011						593,040	2,245	14,120	282,080	117
		01 April 2011	Magnitude 2.3 seismic event									
		04 April 2011	Deformed casing confirmed with caliper 8480-8640ft MD (just below zone 3)									
3	DFIT	08 April 2011	8,420	8,489	8,340	27	81	10,668	40	254		
	Job	09 April 2011						200,634	759	4,777	116,480	52
4	DFIT	25 May 2011	8,020	8,259	8,052	27	81	21,084	80	502		
	Job	26 May 2011						423,696	1,604	10,088	183,680	82
		27 May 2011	Magnitude 1.5 seismic event									
5	DFIT	27 May 2011	7,970	7,819	7,823	27	81	11,760	45	280		
	Job	27 May 2011						402,780	1,525	9,590	248,640	111
6	DFIT	31 May 2011	7,670	7,789	7,666	27	81	10,290	39	245		
TOTALS							513	2,218,902	8,399	52,831	1,037,120	463

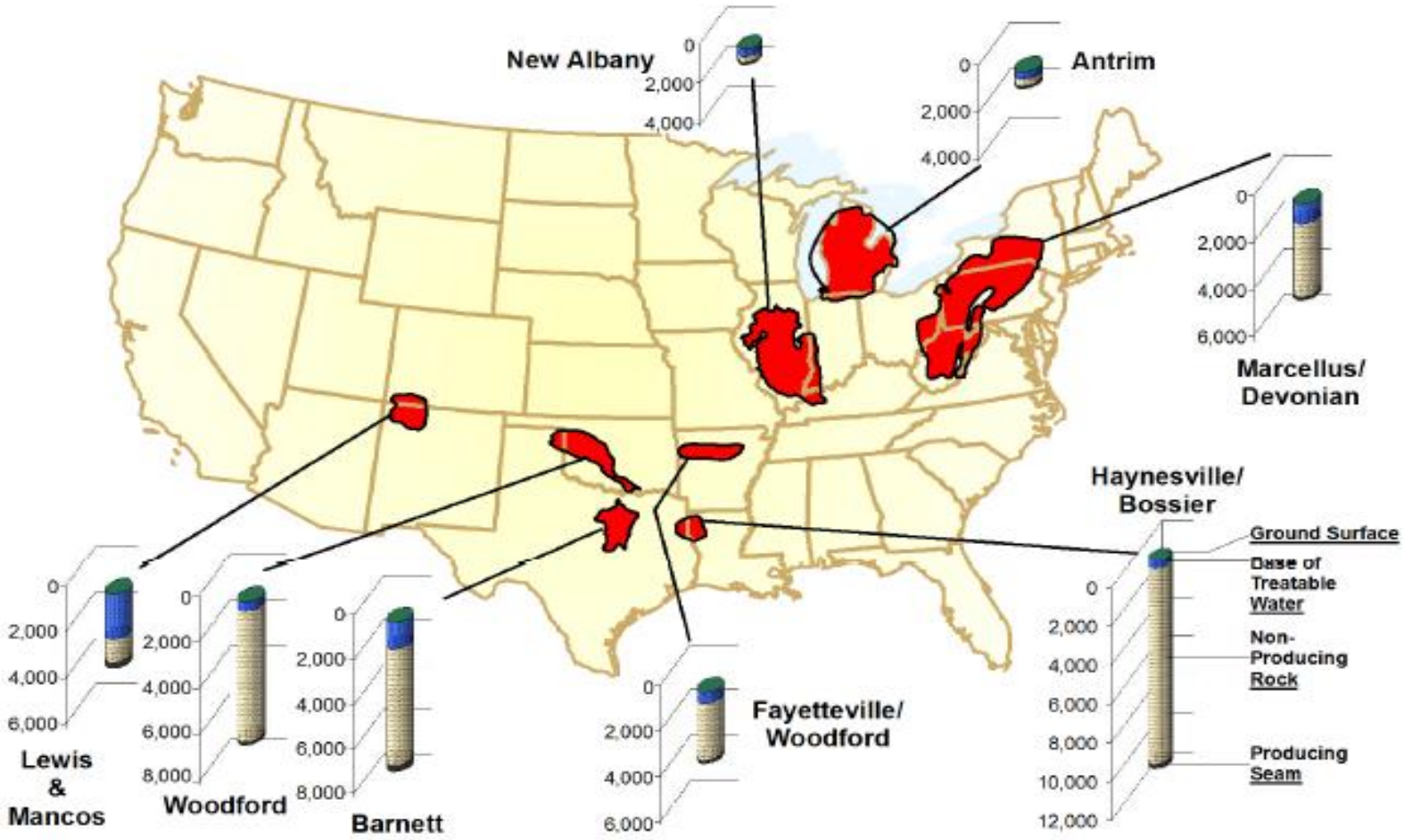
Injection volume and seismicity during treatment stages.

- Earthquake activity closely correlates with stages 2 and 4.
- The largest event with 2.3 M_L at 02:34 on 1/4/2011 occurred shortly after stage 2.

Earthquake activity was caused by fluid injection into a fault zone

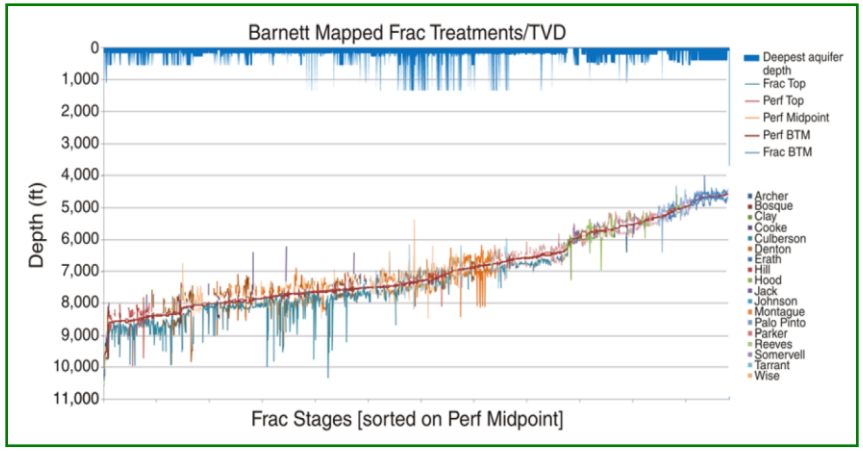
- The fault failed repeatedly in a series of small earthquakes.
- The fault is yet to be identified.

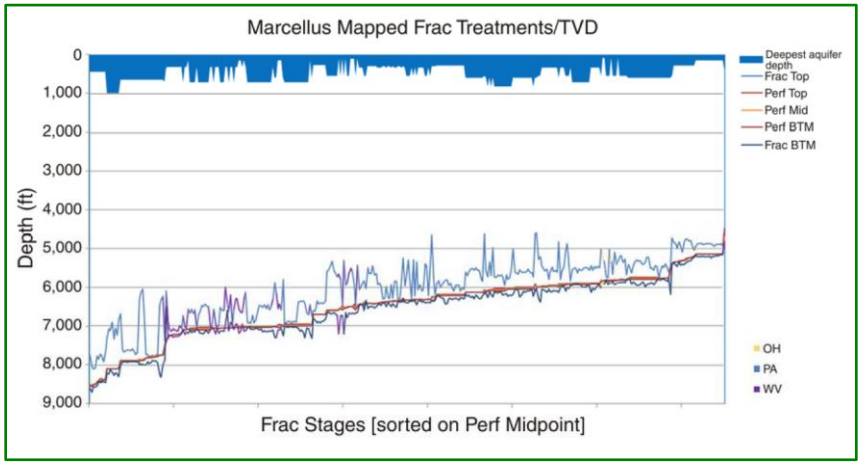
FRACTURING & AQUIFERS

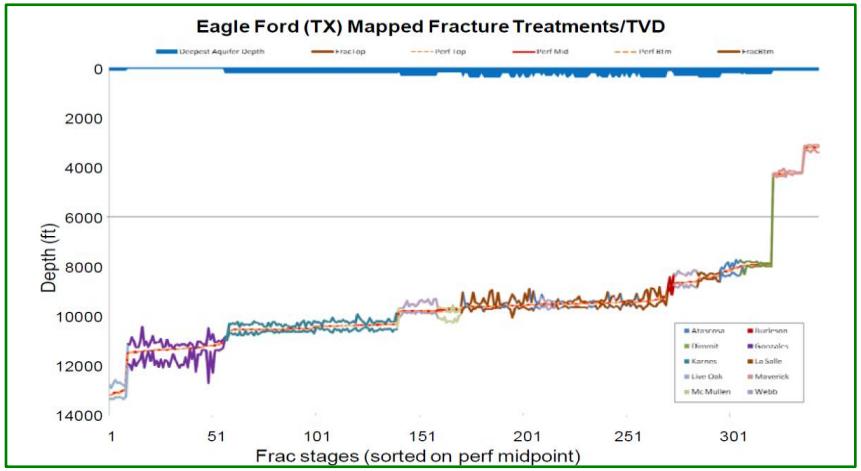


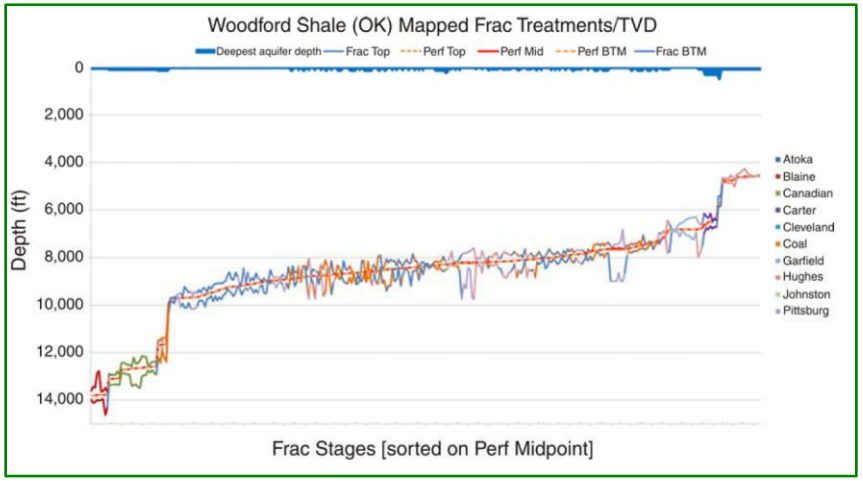
(Source Shale Gas PRIMER)

FRACTURING & AQUIFERS









(SPE 145949, Fisher and Warpinski, 2011)

SUMMARY

FRAC DEVELOPMENT BEST PRACTICES

Based on US experience:

- **Formal Risk/Impact Assessment of well drilling and completion operations**
- **Geophysical logging**
- **Surface casing strings and packers/cement to protect aquifers**
- **Completion designed to prevent upward migration of reservoir and injected fluids**
- **Good cement: testing of each completion string**
- **Fluid storage in tanks/protected pits**
- Fracture diagnostics
- Avoidance of fracturing near faults/subsurface structures
- Reuse of frac fluid
- Local water sampling
- Regular updates and frequent engagement with stakeholders

INDUCED SEISMICITY - TRAFFIC LIGHT SYSTEM