Optimal Perforating Design for Hydraulic Fracturing and Wellbore Connectivity in Gas Shales

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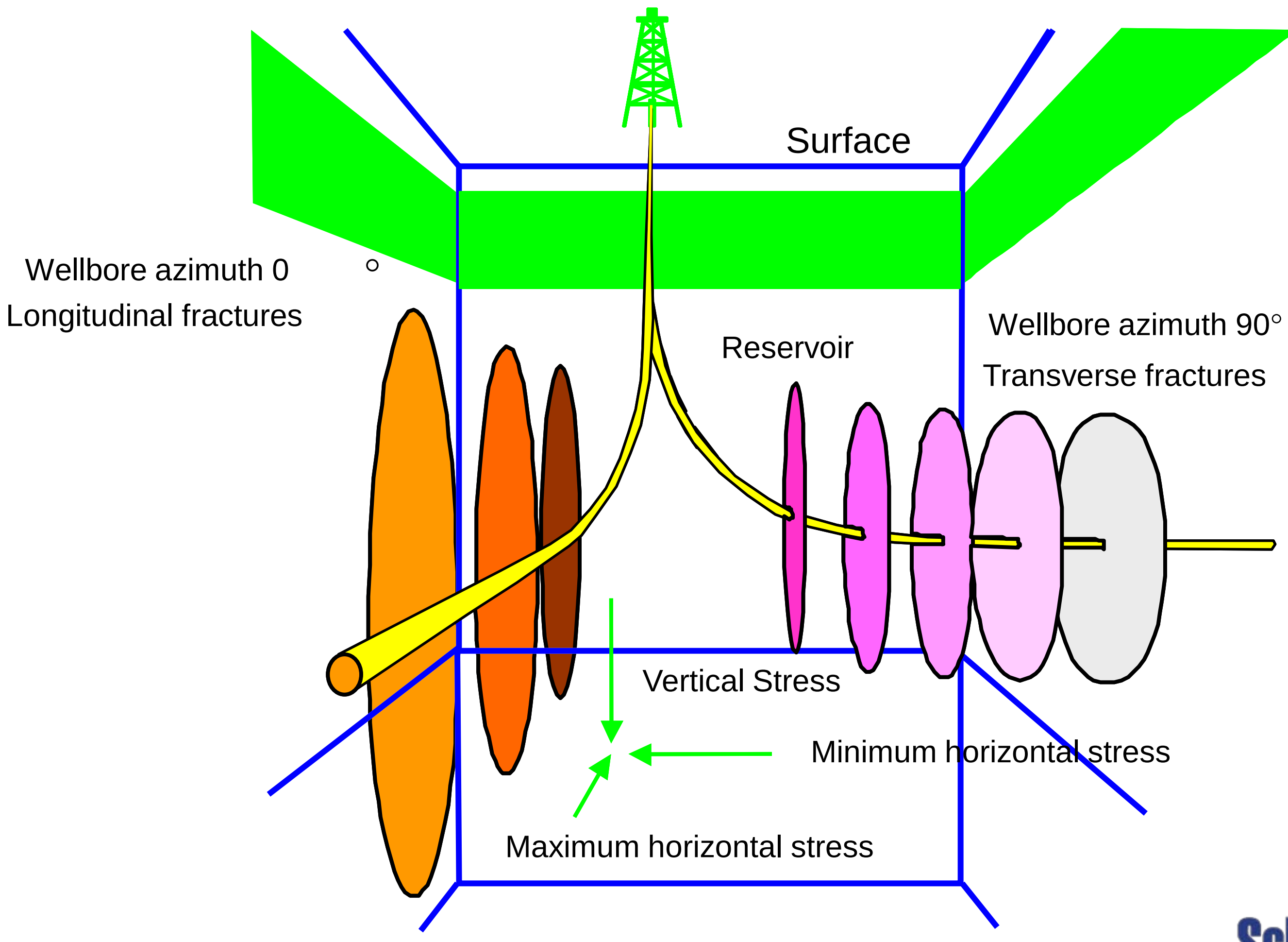
Hydraulic Fractures In Horizontal Wellbores

Goal is to Create Surface Area



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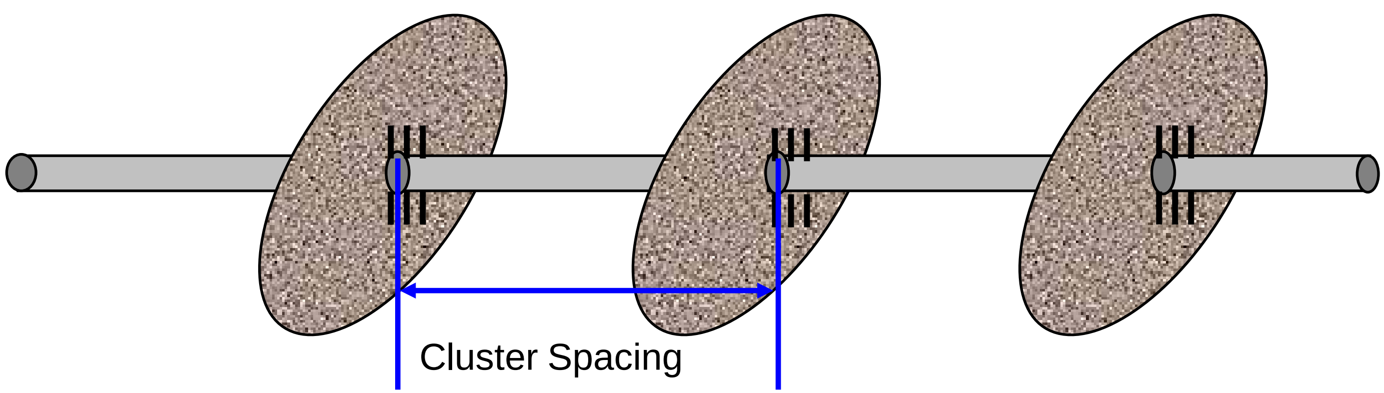
Perforating-for-Fracturing Issues

•Wells are horizontal and fractured in 3-5 stages

•Each stage has 3-5 perforation clusters

•Each cluster is about 2 ft of perfs at 6spf and 60^o phasing

- How many perfs in a cluster?
- Orientation of perfs?
- Connectivity with fracture
- Depth of penetration in shales
- Open or closed perforation tunnels
- Impact of perforating on fracturing and productivity



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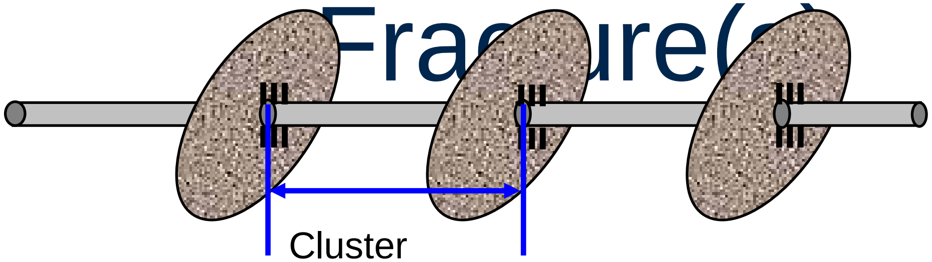
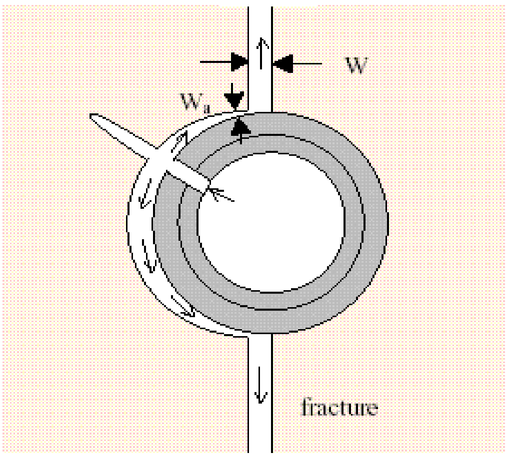
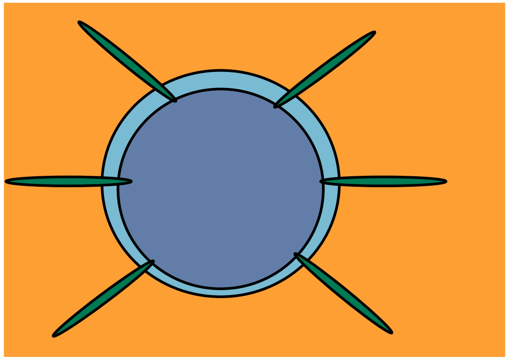
Connection with the Fracture(s)



Longitudinal fracture



Transverse fracture



Poor connectivity can induce

- Pressure loss during pumping and production
- Screen-outs

Can be mitigated by

- Acid Soluble Cement
- Careful design of Perforation Clusters and Phasing

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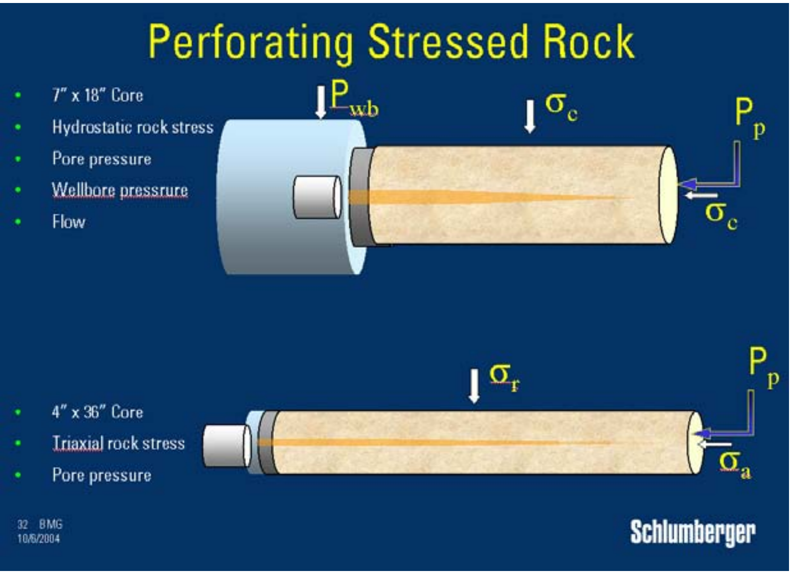
Perforating Experimental Facilities

- Three stressed single-shot pressure vessels (SRC)
- Three poly-axial stress frames (SRC and TerraTek)



Shale Perforating Flow Tests – Composite Pierre Shale-Sand Targets

Perforate and flow through a composite Pierre shale-sand target.

- No production with 2000 psi drawdown.
- Perf tunnel through shale plugged!
- Confining stress = 6500 psi.

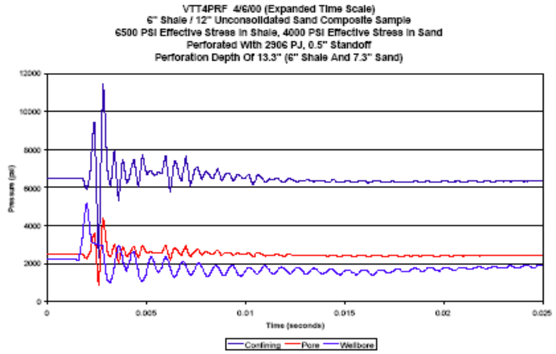


FIGURE EIGHT
Test Four shot-Time Pressures (expanded scale)

FIGURE NINE
Perforation Through The Shale Section – Test Four

Shale Perforating Flow Tests – Composite Mancos Shale-Sand Targets

Perforate and flow through a composite Mancos shale-sand target.

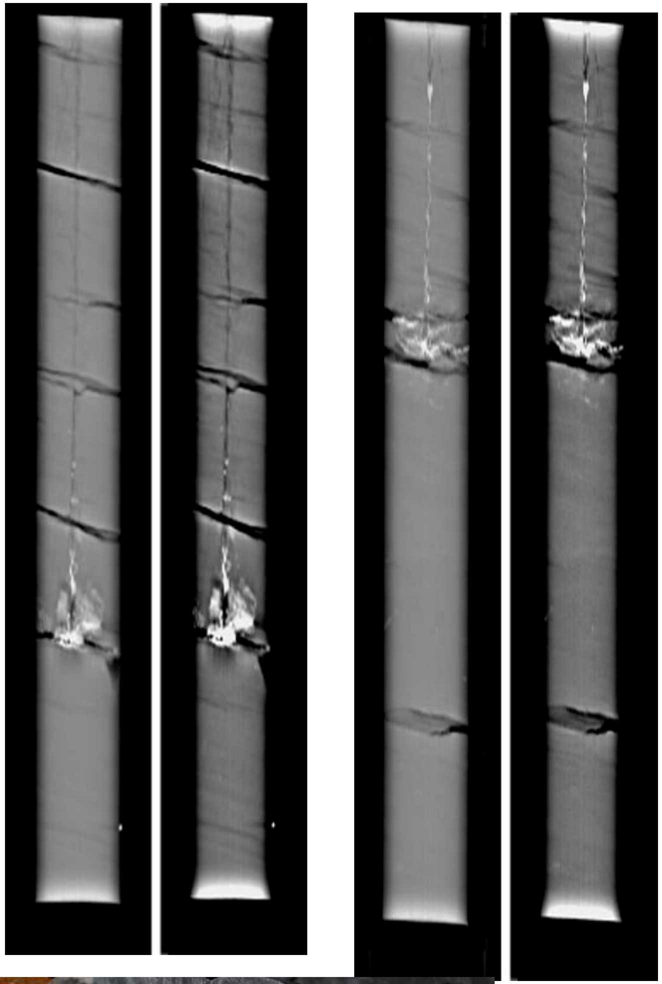
- No production with 2000 psi drawdown.
- Perf tunnel plugged!
- Confining stress = 6500 psi.

FIGURE SIX
Picture Of Shale Cap Rock From Test Five Split Open
(Disturbed area is outlined for clarity)

Shale Perforating Tests

Tests to determine depth of penetration and hole diameter: best charge?

- Stressed Mancos shale.
- Deep penetrator charge: 12.5”.
- Research charge: 6.7”-8.4”.
- Narrow hole full of loose material after perforating, but the fill is more solid when left stressed for 24 hrs.
- Similar results with Pierre shale, but wider, longer tunnel.
- Update: small BH charge provides open tunnel but little penetration



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Proposed Initial Single Shot Tests

Communication – fracture breakdown test – two tests (DP & BH).

- Similar to the perforating flow tests, but with injection.

  If no injection, increase pressure to try and breakdown.

Evaluation of tunnel closure after 24 hr. – Four tests.

- Similar to the previous tests, but with different shales with BH and DP charges.
- Two shales and two charges.

Perf/Frac Testing

A combination of single shot hydrostatic, small block triaxial and large block triaxial fracture tests.

- Focus on shales and horizontal wells.
- Objective: Determine perforating parameters that will:
  - A) Minimize fracture initiation,
  - B) Maximize fracture-to-wellbore connectivity and
  - C) Have acceptable perforation pressure drop.

Large Block Perf-Fracture Tests

Naturally fractured Mancos shale

- Cased hole, 4.75” borehole, 3.5” casing.
- Shale drilled under stress.
- 2” perforating gun(s)

Issues

- How do fractures initiate and connect to the wellbore?
- Orientation: Is shooting 0-180° or in transverse planes better than 60° spiral?
- Does penetration matter? Do fracs really originate at the base of perforation tunnel? Do perf tunnels close up?
- Does a longitudinal frac always initiate first?
- What affects fracture initiation pressure?

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Proposed Initial Three Small Block Tests

Objective

To determine perf-to-frac connectivity versus gun phasing.

- Sixty degree spiral phasing.
- Oriented top-bottom 180 degree phasing.
- New perforation system.

First Large Block Cased Hole Test

Objective: Simulate spiral phasing to evaluate fracture initiation and wellbore-fracture connectivity.

Validates first small block test.

- Uses best charge type from single shot tests.
- Shoot one foot gun, 60 deg phase, 6 spf.
- Obtain fracture initiation pressure.
- Flow through fracture to obtain pressure drop versus flow rate.
- Map fractures

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Second & Third Large Block Tests

Simulate 180^0 up-down phasing and new perforating system

- Uses best charge type from single shot tests.
- Shoot one foot gun, 180 deg phase, 4 spf.
- Obtain fracture initiation pressure.
- Flow through fracture to obtain pressure drop versus flow rate.
- Map fractures

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Additional Tests

Rock mechanical properties tests.

XRD & CST for fluid compatibility.

Fracture mapping.

CT-scan as needed.