Perforation Flow Laboratory:
Six Decades of Insights into Field Perforating Performance

Brenden Grove, Larry Behrmann, David Atwood, Andy Martin, Philip Kokel, Jeremy Harvey, Thomas Christensen

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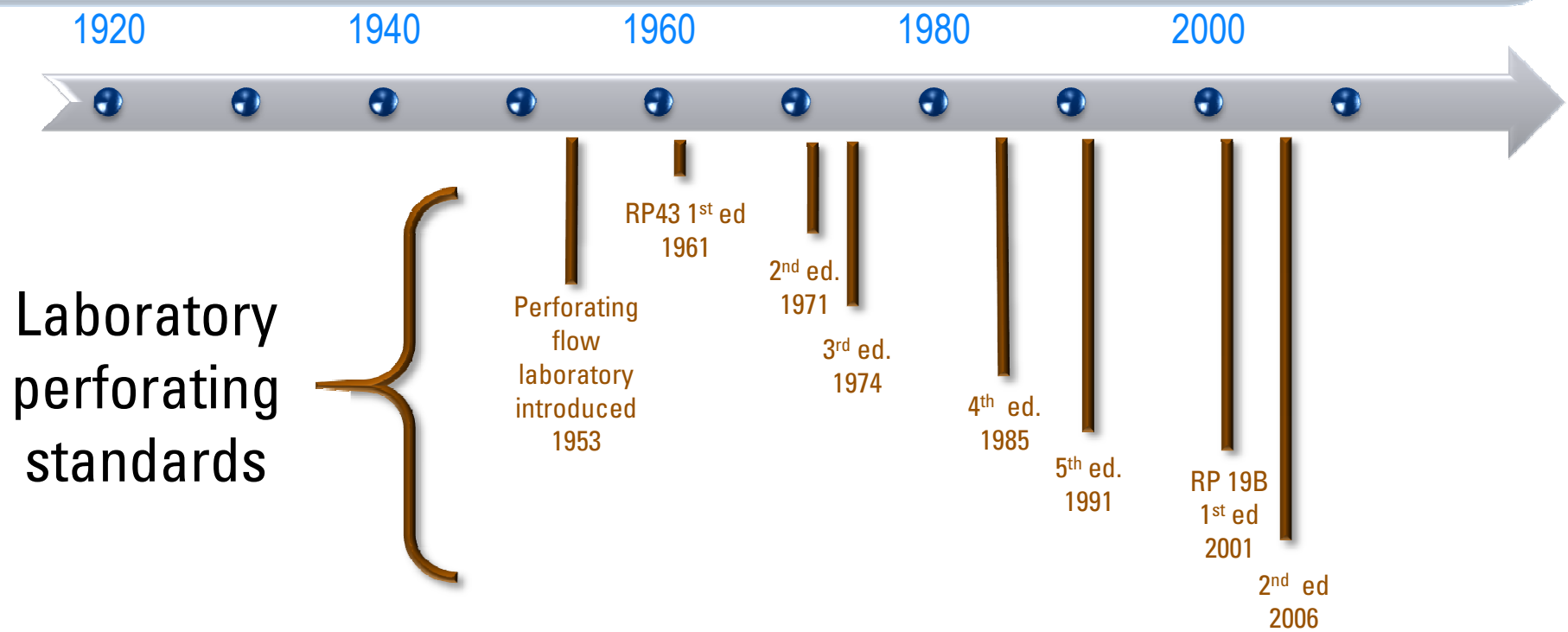
Perforating Flow Laboratory – 6 Decades and Counting

- Historical context
- Capability evolution
- Advances & milestones
  - relevance to field, benefit to industry
- Common themes
- Outlook for the future

Perforating Flow Laboratory – Historical Context

Field perforating techniques

Mechanical (knife cutter)		
Bullet	1932	Niche applications
Shaped Charge	1948	>95% of all perforating
Hydraulic (abrasive jetting)		Niche applications



Perforating Flow Laboratory – Evolution of Test Standards

WellFlow Index (WFI) Linear flow

Core Flow Efficiency (CFE) Linear flow

Radial flow also conducted

Bell et al. 1972
Regalbuto et al. 1985
Liu et al. 1988
Deo et al. 1989

Halleck et al. 1997

Core Flow Efficiency Radial or Linear flow

1920 1940 1960 1980 2000

RP43 1st ed 1961

2nd ed. 1971

3rd ed. 1974

4th ed. 1985

5th ed. 1991

RP 19B 1st ed 2001

2nd ed 2006

Section 1 — Concrete: penetration

Section 2 — Rock: penetration & flow

Then…

1 Concrete: penetration

2 Rock: penetration

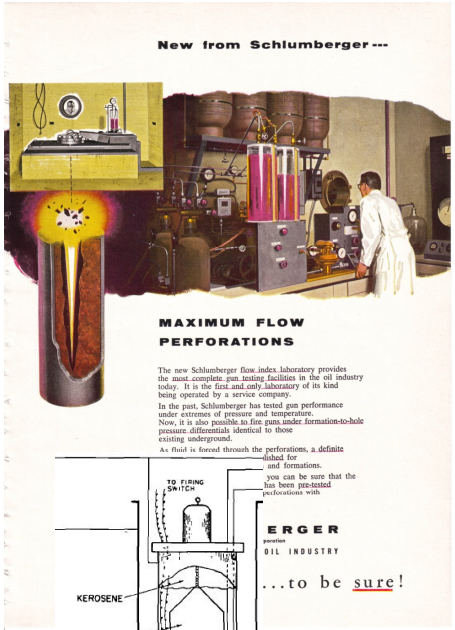
3 Temperature

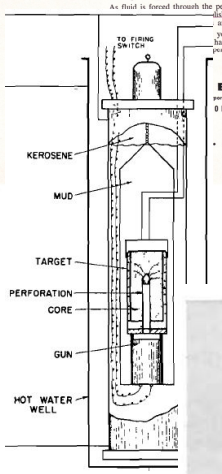
4 Flow

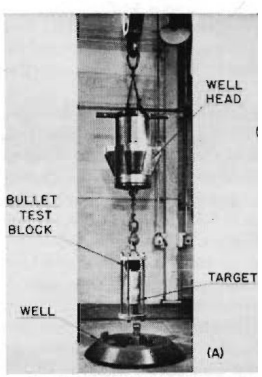
5 Debris

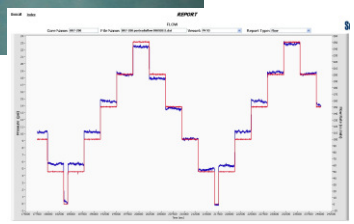
Now…

Perforating Flow Laboratory – Evolution of Lab Capabilities



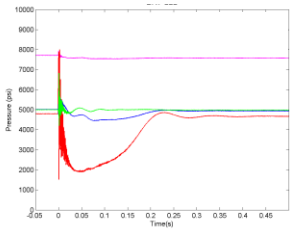


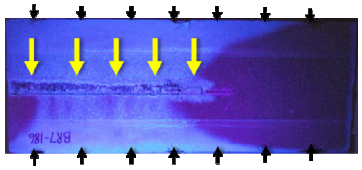


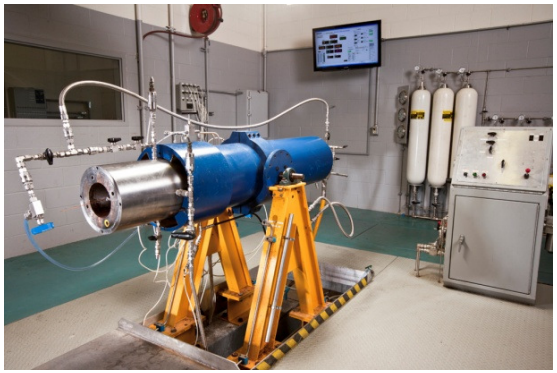


- Independent control of confining, wellbore P
- Perforating gun system (multiple charges)
- Transient pressure measurements
- Transient pressure control
- Precision flow control
- automation
- Flow visualization

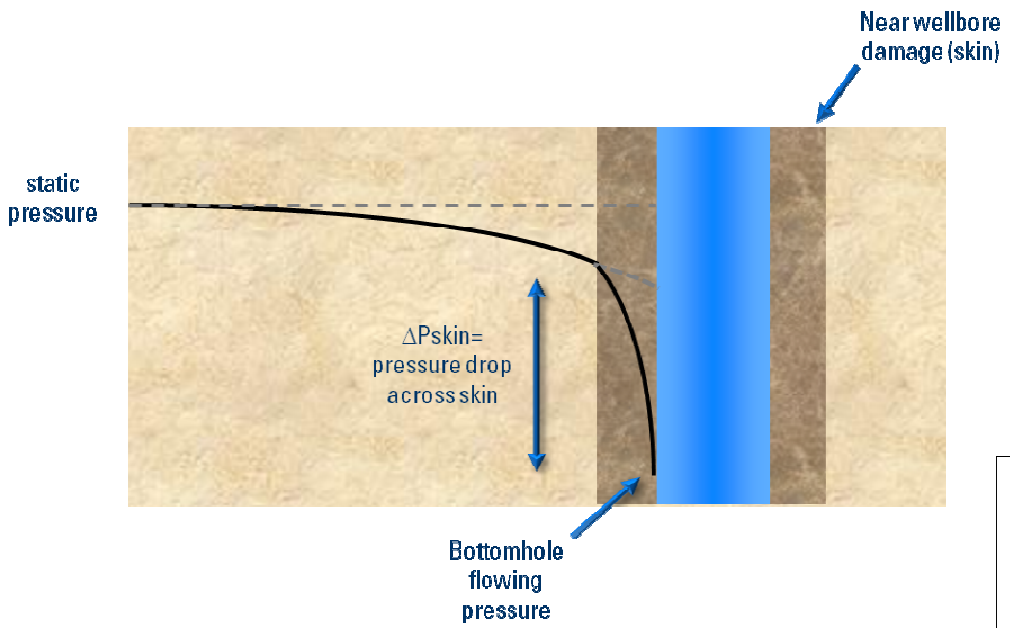
1940 1960 1980 2000

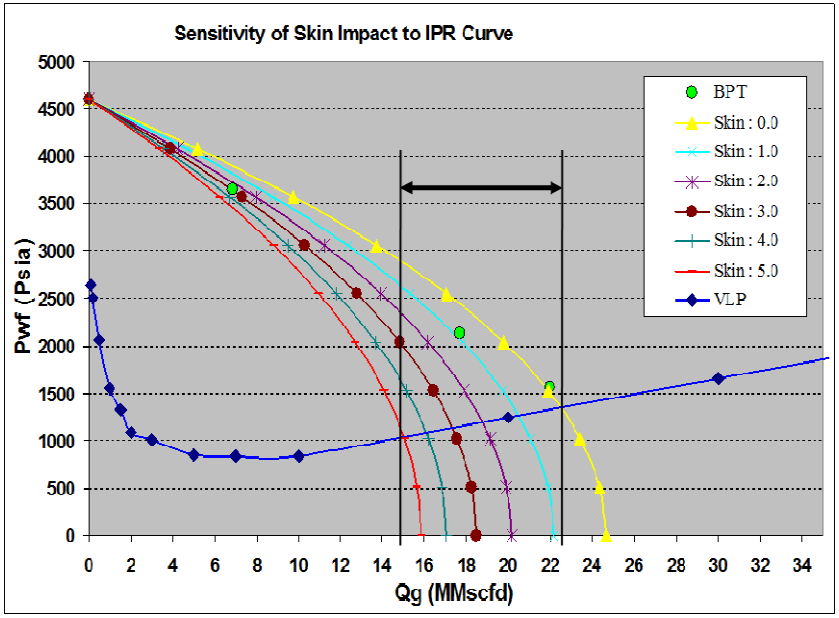






Productivity & skin

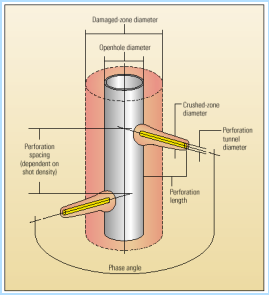




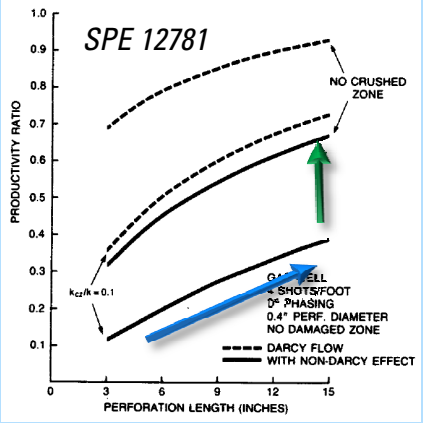
Reduce skin = increase production

Productivity & skin

Natural completions

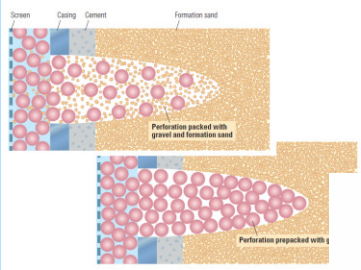


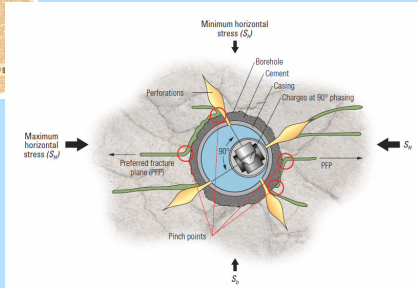
- Shot density
- Phasing
- Penetration depth
- Perforation damage



Stimulated completions

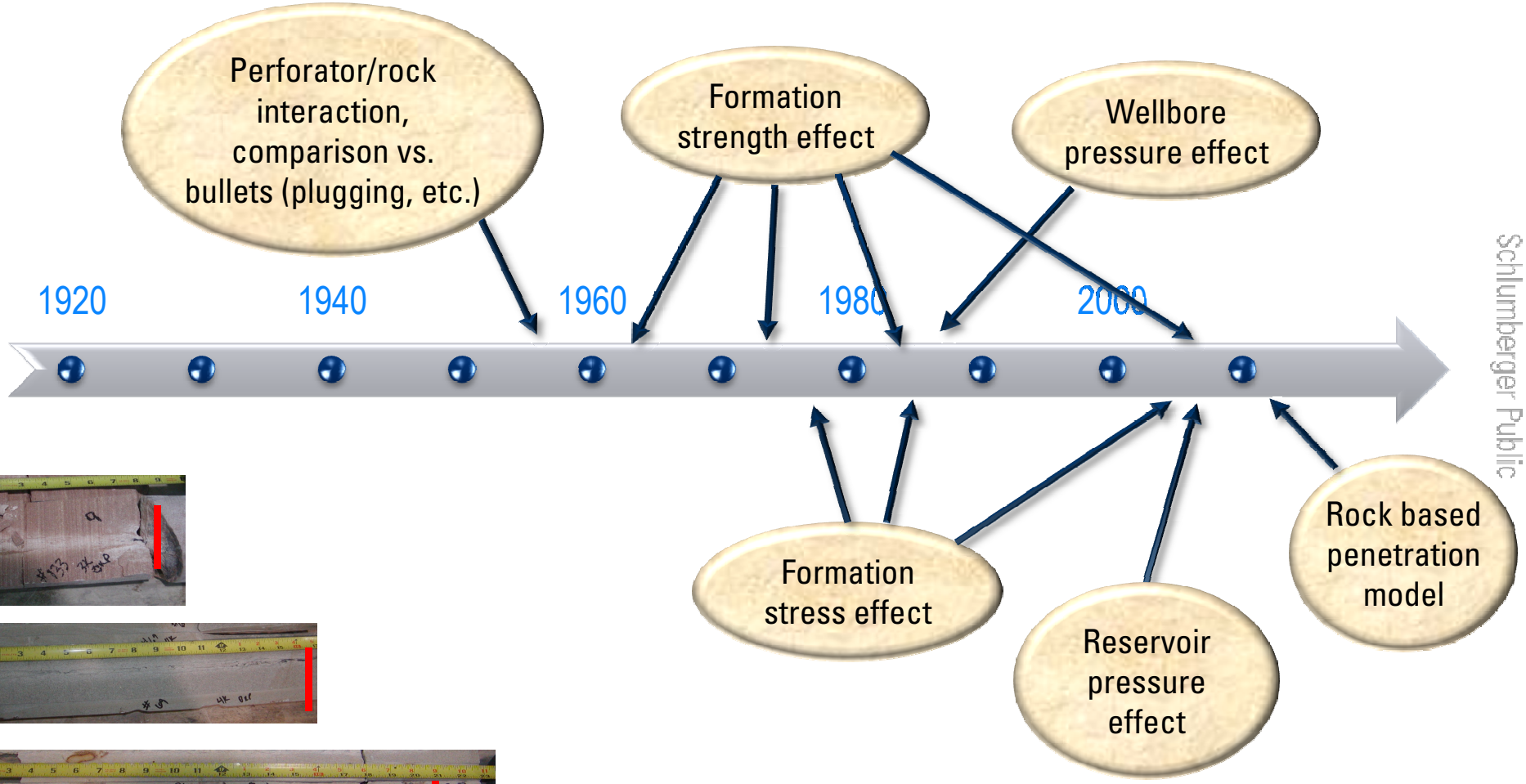
- Weak rocks – sand control (GP / FP)
- Tight rocks – hydraulic fracturing
- Carbonates - acidized

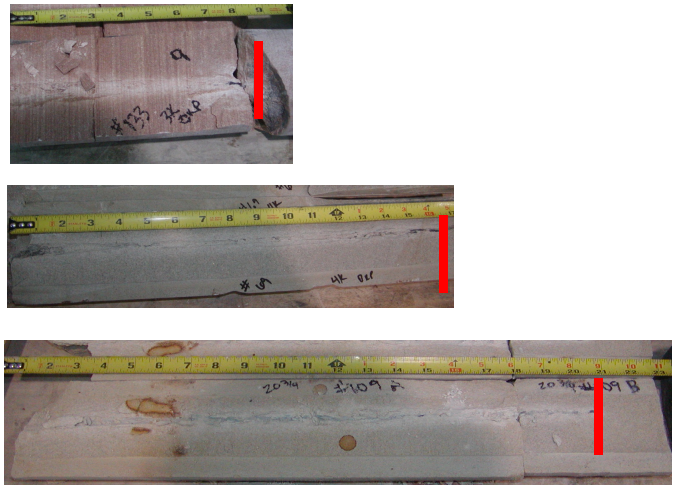




Perforating Flow Lab - Fundamental Advances in Industry Knowledge

Penetration related

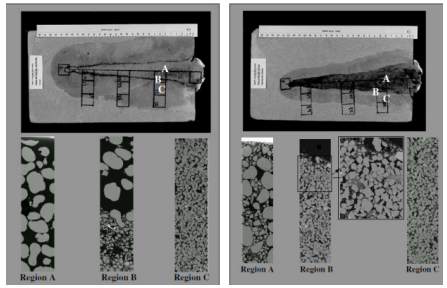


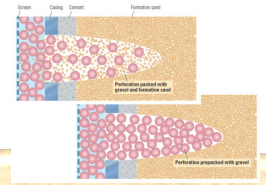


Penetration depth = f (formation strength, stress, reservoir pressure, etc.)

Perforating Flow Lab - Fundamental Advances in Industry Knowledge

Cleanup, skin, & completion related

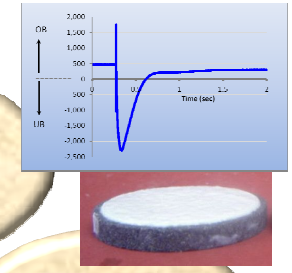




(late 80's)

carbonates / acidizing (2000s)

Perforating strategies for stimulated completions



Integrated perf + fluids (2004-5)

1920 1940 1960 1980 2000

Fundamental nature of perf damage (2011)

Static UB known to be important since 50's

Static underbalance skin (1991)

optimum static underbalance (1995)

Dynamic underbalance discovered (~2001)

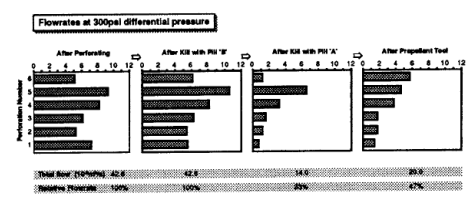
Perforation cleanup

Static UB not required!!

production through the perforations. High productivities are indicated when jet perforating in oil or salt water with pressure differentials into the well bore using a perforator which does not cause carrot plugging.

Allen & Worzel (1956)

Multiple perfs (all perfs are NOT created equal) (1994)

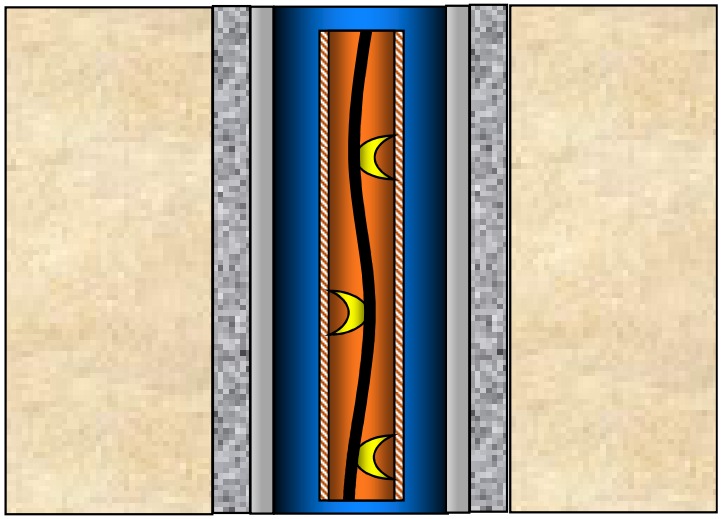


Common Theme & Goals

- Theme
  - Perforating is a SYSTEM operation

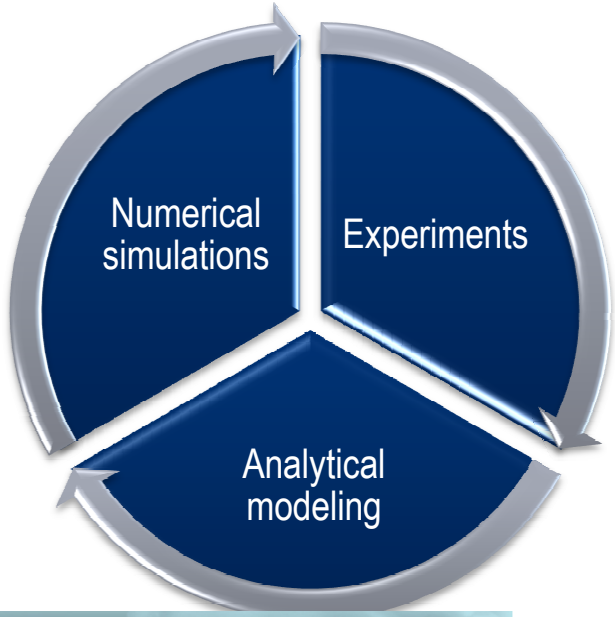
System =
Gun & charges
+
Wellbore
+
reservoir

- Goals:
  - Understand reservoir response
  - Understand wellbore & completion responses

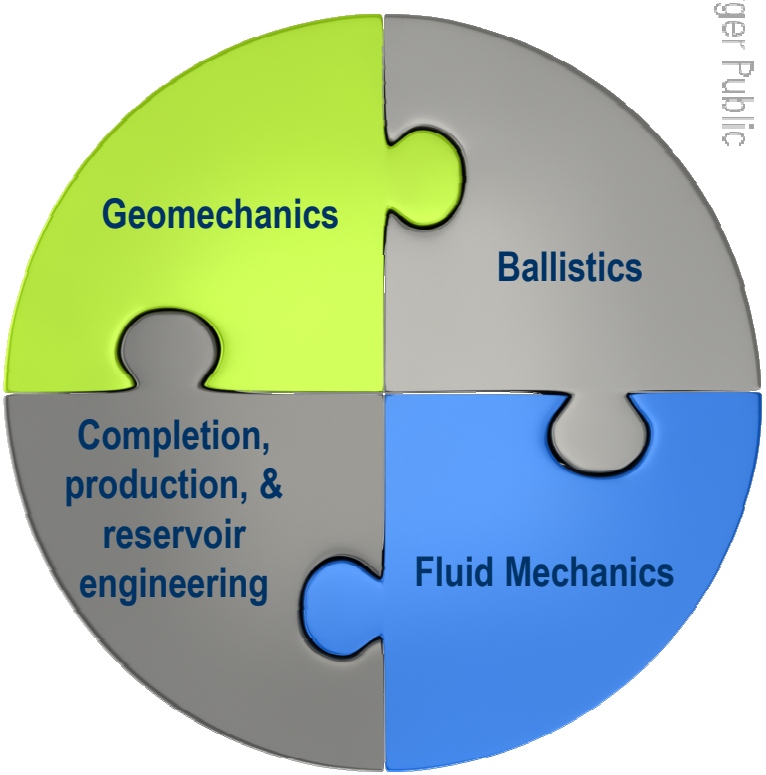


Keys to Success

- Know what to measure & control
- Measure & control it
- Interpret, and ultimately apply to downhole
- Integration

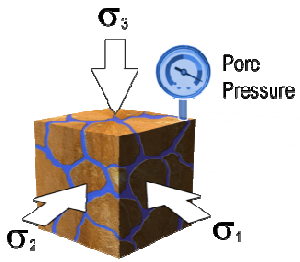


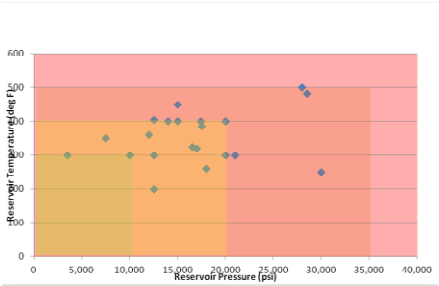
System = gun + charges + wellbore + reservoir



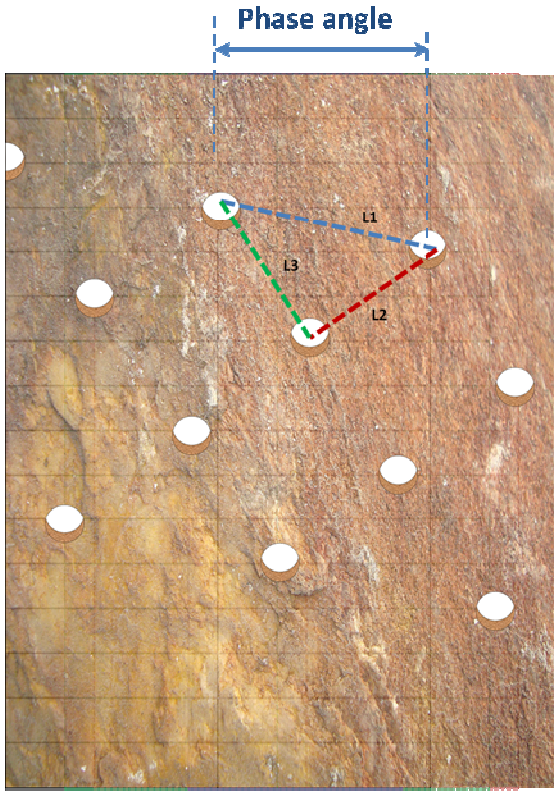
Recent & Future Trends

- More accurately replicate downhole environment
  - Formation properties
  - Dynamic conditions
  - Fluids
  - Drilling damage





- Harsher environments (HP, HT)
- Prove product (and system) performance, validate models
- "test drive" perforating techniques, before field trial
- Evaluate sanding potential; life-of-well studies
- High rate gas



Ultimate Goals Remain the Same

Well Performance

Productivity, injectivity
- Well skin
- Penetration
- Perforation efficiency

Reliability

Well performance over the long term
- Flow efficiency deterioration
- Sanding

Ultimate

Operations

Perforating
- Efficient well control
- Gunshock

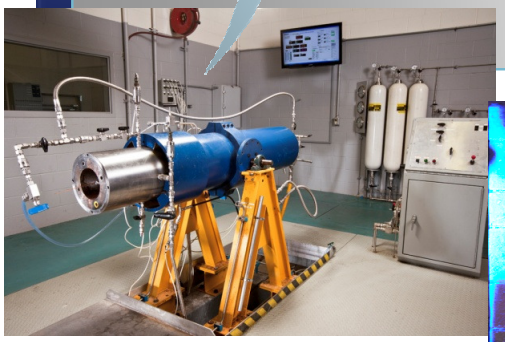
Life of well
- Sand production
- water

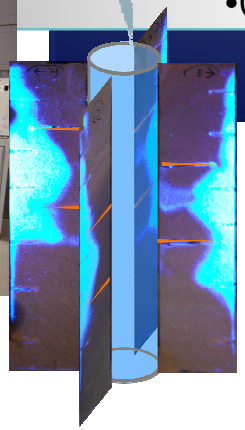
Safety

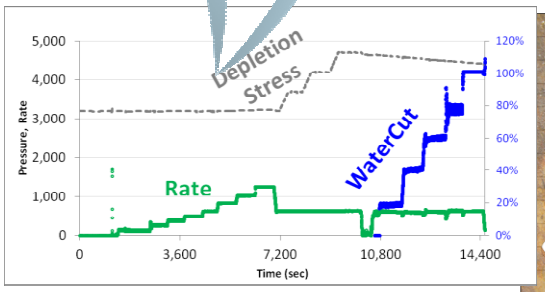
Well control during perforating

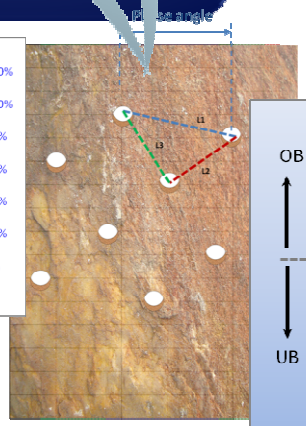
Explosive [illegible]ure at [illegible]

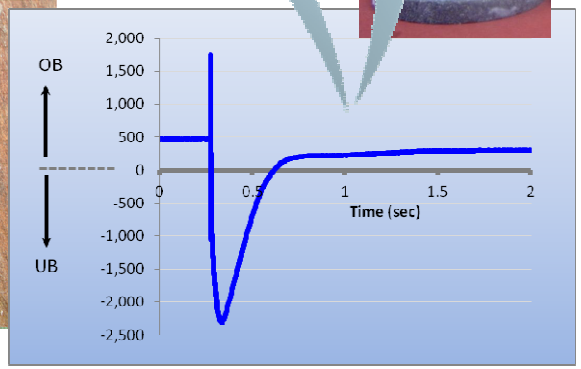
- N[illegible]al producer[illegible]ni[illegible]tors
- Sti[illegible]lated (frac'd, ac[illegible]ed)
- Sand p[illegible]vention / sa[illegible] co[illegible]l
- Convention[illegible] / unconve[illegible]ional / H[illegible]T





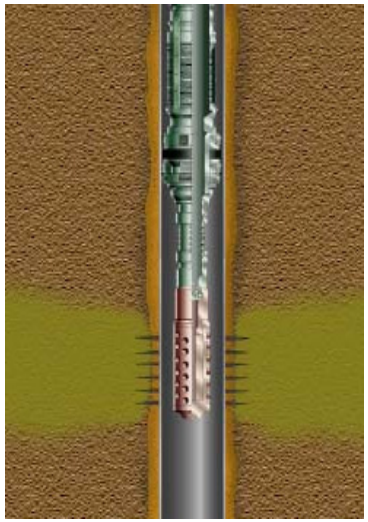






Summary

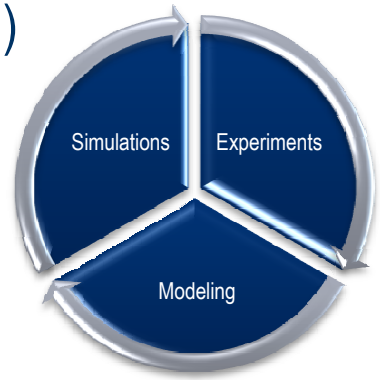
- Perforating flow laboratory, 6 decades of:
- Fundamental discoveries
  - Penetration depth
  - Perforation cleanup
- Field techniques developed / demonstrated / refined
  - Natural completions
  - Sand control
  - Hydraulic Fracturing
  - Acidizing
- Predictive models developed / validated / calibrated



Integration essential (multidisciplinary; expts+modeling)

Reduce risk & uncertainty for field operations

Relevance to field is key!



Outlook

- All of this will continue – and become more important in the future, as:
  - Field conditions get more severe
  - Accurate prediction of downhole performance becomes more critical
  - Operations get less risk-tolerant
- Laboratory testing can be essential piece of the puzzle:
  - Ensure the optimal technology is selected for field application
  - Improve confidence in expected field performance

Maximize well productivity & operational efficiency

Minimize risk to field operations and completion equipment

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Thank You

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