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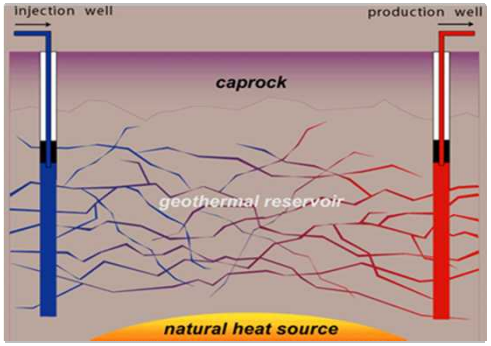

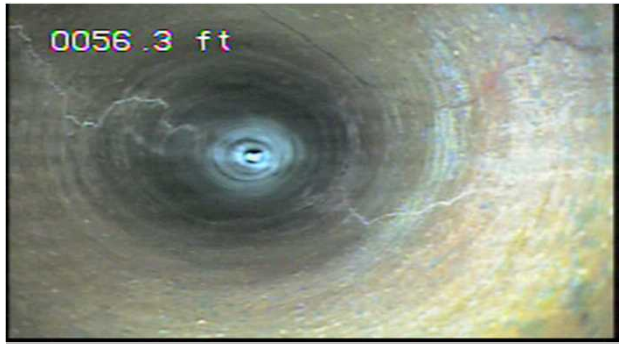

An Overview of High Energy Stimulation Techniques for Geothermal Applications

Mark Grubelich, Geothermal Research, mcgrube@sandia.gov

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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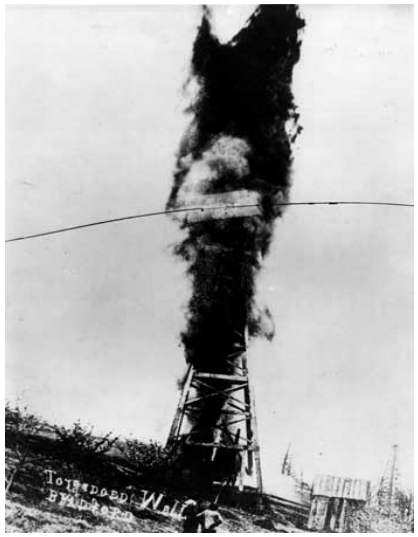
History

- 1846 Ascanio Sobrero: Nitroglycerin invented, thought to be inert. Oops!
- 1859 Col. Edwin L. Drake completed the first well drilled specifically for oil.
- 1865 Col. E.A.L. Roberts made the first successful oil well shot on the Ladies Well, using 8 pounds of black powder (nitroglycerin was first used 2 years later), ushering in the era of "Oil Well Shooting".
- 1947 early hydraulic fracturing >50years> 1997 modern hydraulic fracturing developed
- Sandia develops Tailored Pulsed Loading blended gun propellant(dp/dt)
- 1980's a geothermal well is stimulated with HE and is ruined it. This is not good!
- 2004 Autonomous micro-explosives subsurface tracing system. SNL
- Times marches on….



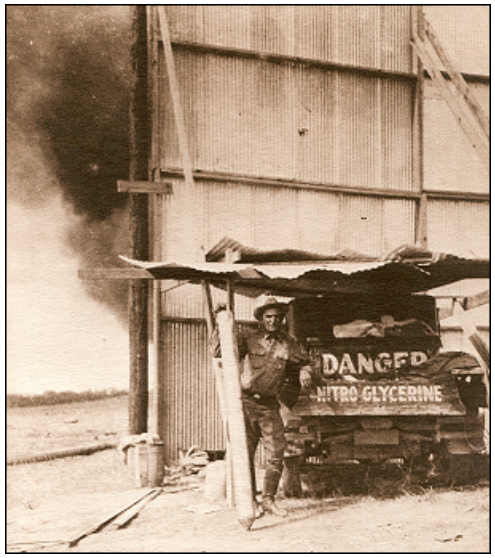
1884-1978

OTTO-CUPLER

OIL AND GAS WELL SHOOTING

TORPEDO CO.

P.O. Box 119
Pleasantville, PA 16341



Energetics 101

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- A review (nomenclature):

Type	Rate (m/s)	Energy Output (cal/g)	Power Output (W/cm^3)
Detonation	$7x10^3$	10^3	10^9
Deflagration	1	10^3	10^6
Burn	10^{-3}	10^3	10^3
Fuel-Air Combustion	10^{-6}	10^4	10

Energetics 102

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- A review:

dp/dt -

Low rate generates single fracture >>Hydraulic fracturing<<
High rate generates multiple fractures >>Energetics<<

Peak pressure

Must be high enough to overcome material properties and in situ stress to promote crack propagation.
Must be low enough to prevent crushing and subsequent well bore damage

High explosive (detonate): A detonation is defined as a reaction wave propagating at supersonic velocity relative to the unreacted material immediately ahead of the reaction zone

Pressure rise can be too fast and too high with solid high explosive

Pyrotechnics & Propellants (deflagrate/burn): A deflagration is defined as a reaction wave propagating at subsonic velocity relative to the unreacted material immediately ahead of the reaction zone

Pressure rise can be too slow and too low with pyrotechnics and propellants

Ideal solution is somewhere between high explosive and propellant.

Hydrogen Peroxide Gas Generator

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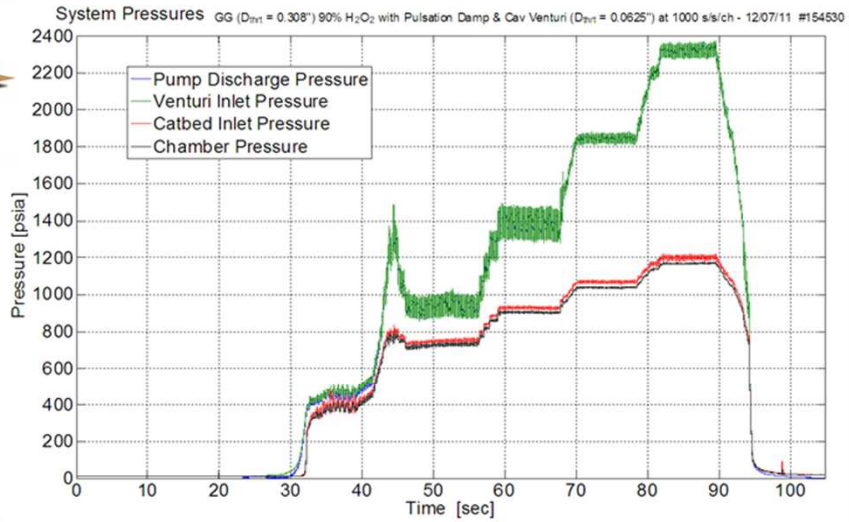
- Where we started:

Maurice J. Zucrow Laboratories
Purdue University



Binary Gas Phase Fuel/Oxidizer Blend

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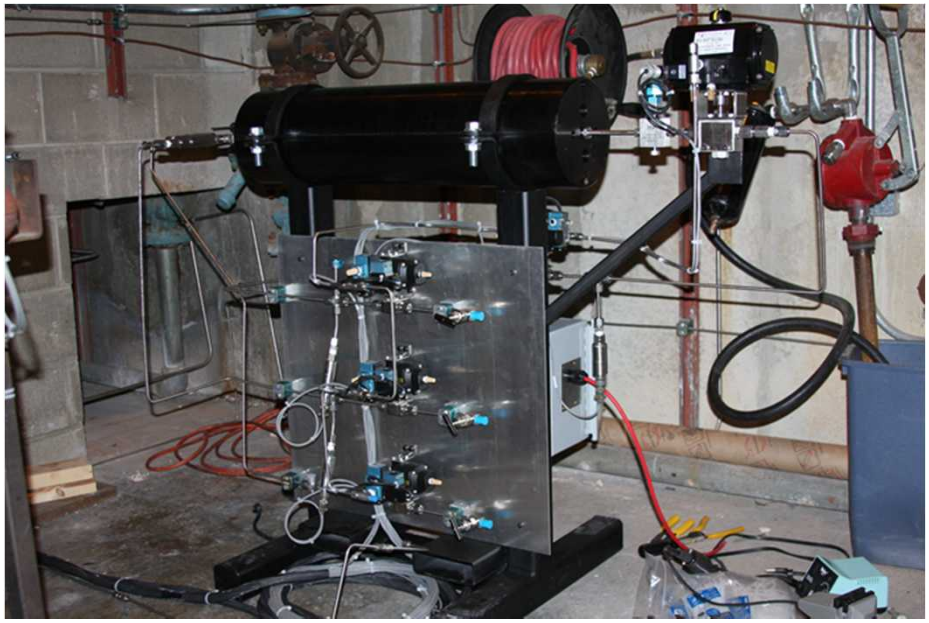
- Where we went:



Short run up to DDT, ~7000 ft/s
Tailored pressure 300 - 80,000 psi

Solid Energetic Materials

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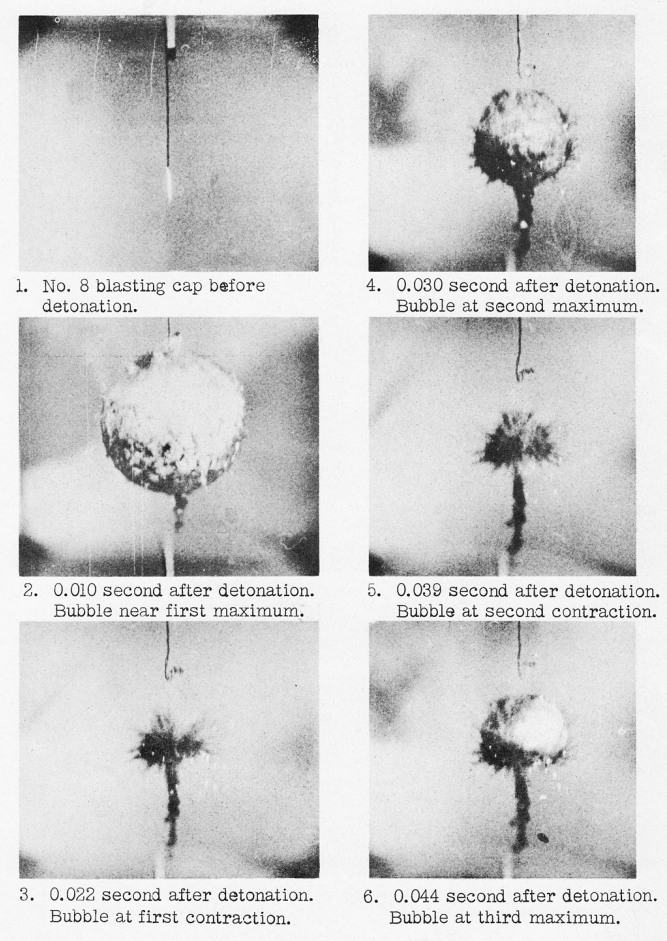
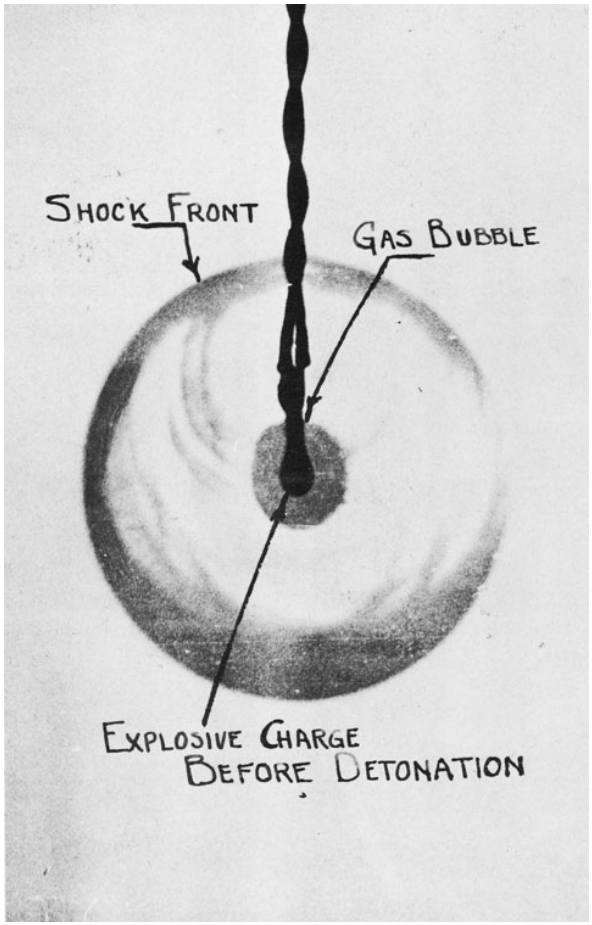
- Where we are:



Detonation bomb calorimeter



Test Site

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- Field testing:

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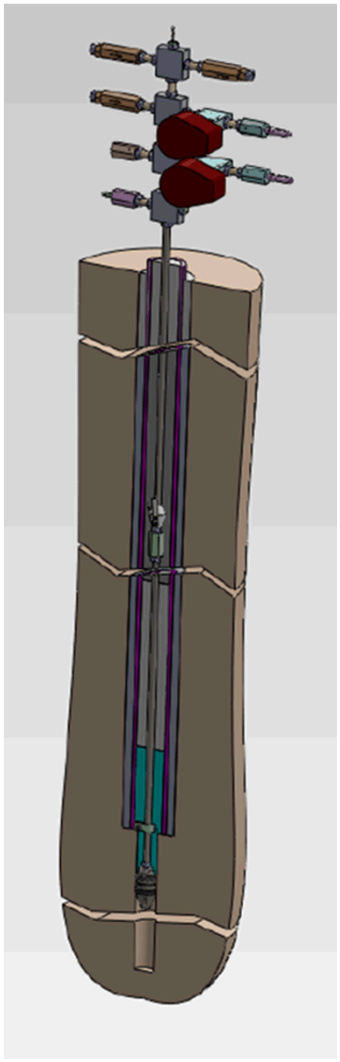


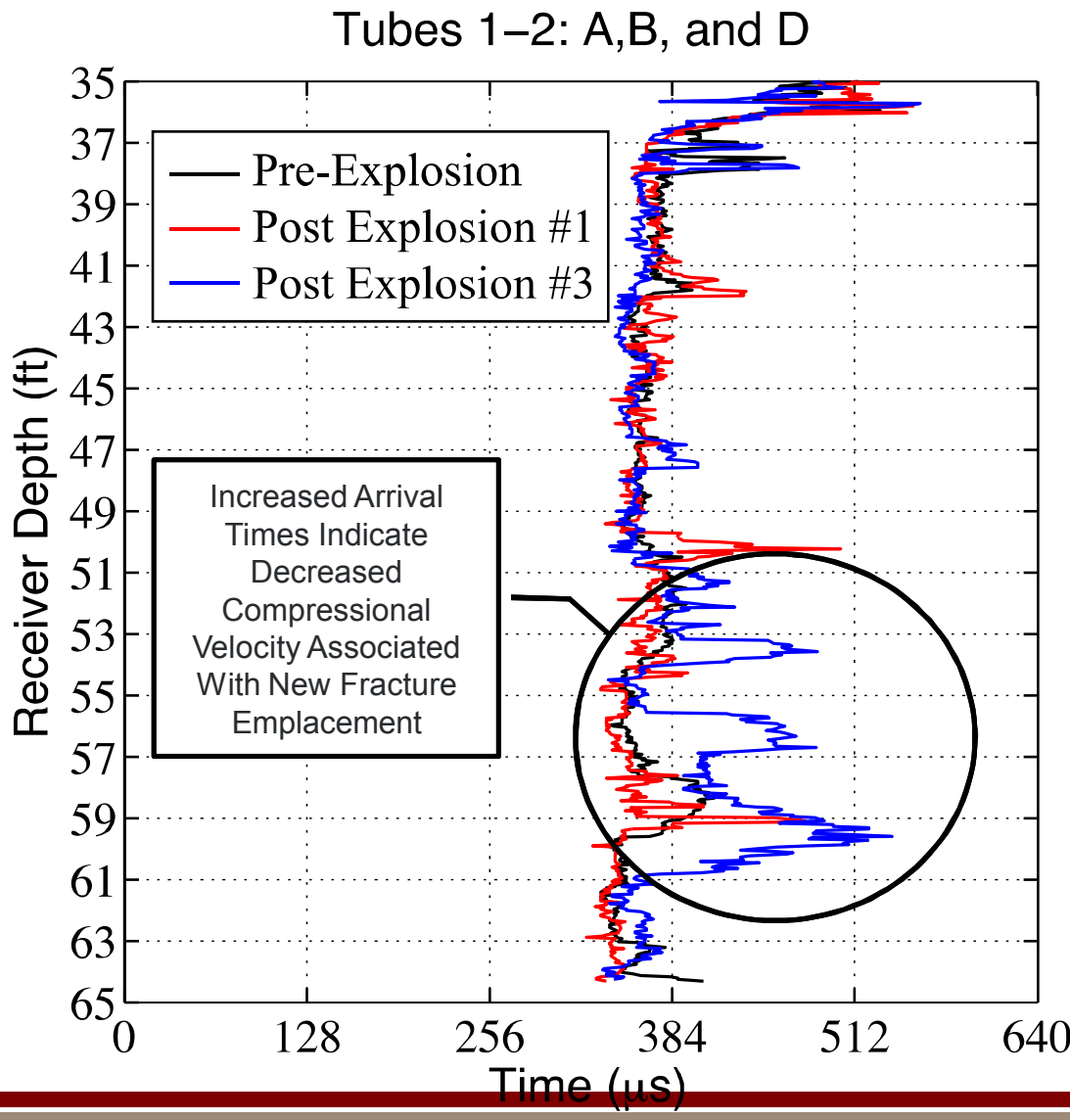
Core Drilling

- Finding fractures:

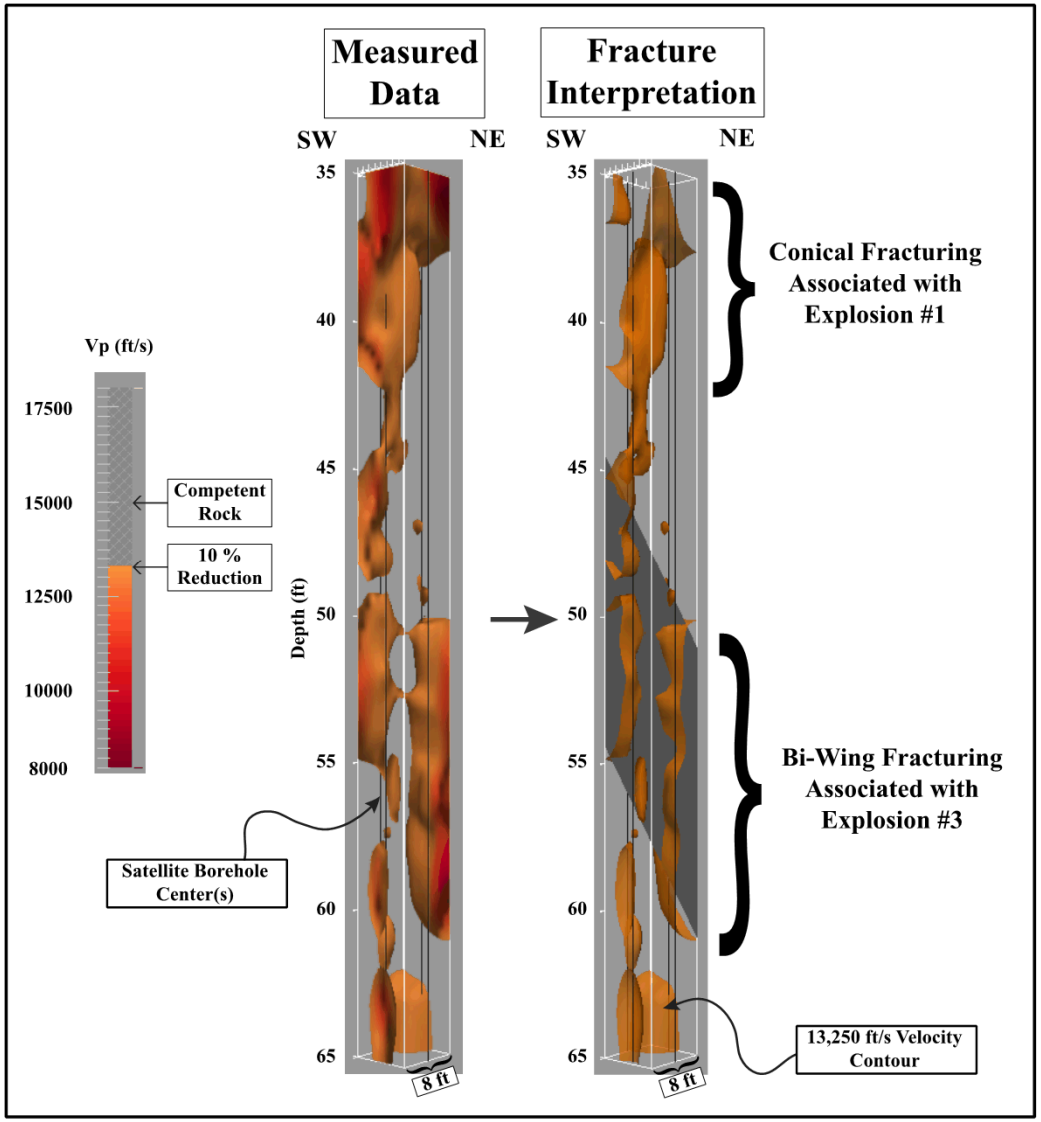
Seismic Imagining

Testing & Data Analysis:

- Four 3-D high-resolution tomographic imaging tests conducted with Cross-hole Sonic Logging (CSL) equipment.
  - Pre-explosion #1
  - Post-explosion #1-3
- 100k waveforms handpicked by subject matter expert and error analysis is complete.
- Environmental changes(i.e. rain/snow fall) shown to effect velocity data.
- Comparison of logging data shows fracture zones at depths coincident to uncased borehole section



Seismic Image Processing and Video

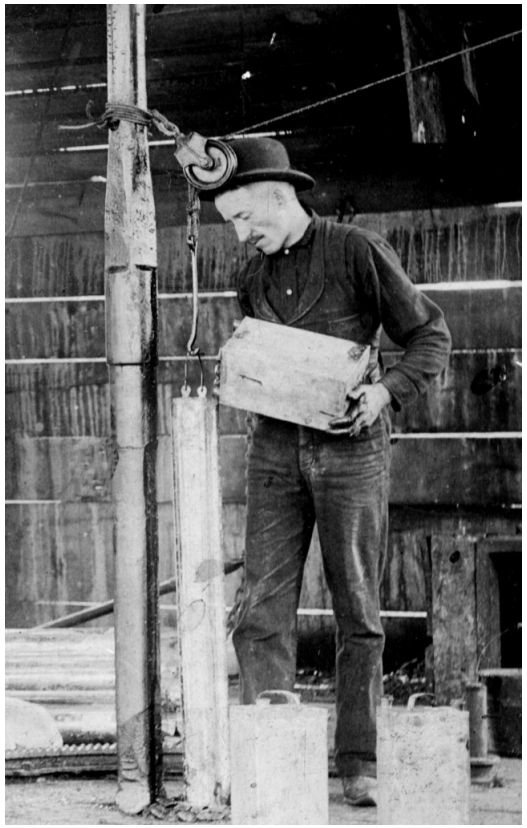


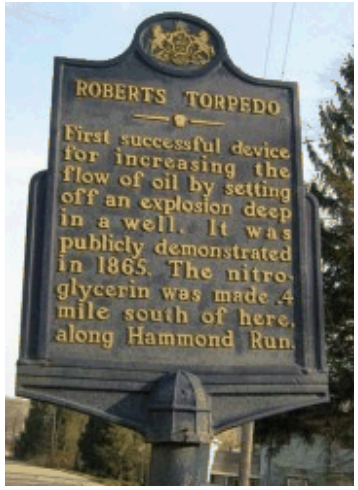
Imaging and Interpretation:

- 3-D high-resolution tomographic image representing dataset post-explosion #3.
- Good Model Fit: 90% variance reduction compared to assumed background model (~16,400 ft/s).
- Geometric interpretation of zones of velocity reductions show:
  - Conical fracture volume above uncased section associated with explosion #1.
  - Bi-wing fracture through uncased section associated with explosion #3.
    - Observation further supported by video footage in shot hole.

Future Directions

- Develop improved energetic formulation
  - Shock pressure reduction & Total pressure increase & Optimized rate
  - More reactive products
  - Less condensables & more non-condensables
- Continued field testing
- Prototype operational hardware
  - High Temperature energetic
  - Wire line capability
  - Integrated system (fireset, charge, etc.)
  - Testing at depth and temperature





Summary

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- Developed high energy fracturing technique
  - Tailored energetics
    - Binary gas phase & non ideal energetics
  - Control of peak pressure and pressure rate demonstrated
  - Tailored reaction products
    - Non-condensable & water reactive
- Lab scale research and field experiments conducted
  - Good scaling!
- Detection of fractures
  - Video
  - Core drilling
  - Seismic imaging
- Progressing to “deep” demonstration test

THE END