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Water-free shale stimulation: Experimental Studies of Electrofracturing

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Introduction

Ultra-low permeability rocks contain vast amounts of hydrocarbons (unconventional resources). The rate of hydrocarbon molecule movement towards a wellbore is extremely slow and impractical without the creation of higher-permeability fracture pathways. We experimentally evaluated ***electrofracturing,*** a non-water-based fracturing method that can be considered "greener" compared to fresh-water-intense hydrofracturing.

Energy Firm Makes Costly Fracking Bet—on Water, from the Wall Street Journal
by Russell Gold, August 14, 2013
"Average amount of water used to hydraulically fracture single Marcellus Shale well: **4.2 million - 5 million** gallons
4.2 million gallons is enough water for a town of 42,000 people for one day
Number of Marcellus Shale wells drilled in 2005-July 2013: 8,700*
Percentage of freshwater used: 90%
Percentage of water recovered from fracks and reused: 10%"
Note: *Includes wells drilled and fracked through May 2013 in both Pennsylvania and West Virginia, but doesn't include every well. Some data are still being processed.
Sources: Susquehanna River Basin Commission via Environmental Protection Agency; W. Virginia Dept. of Environmental Protection

We developed an experimental system to evaluate electrofracturing at pressure using high-voltage pulses applied to rock through a pair of electrodes. This unique test system allows for the application of pulsed high voltages to samples under high pressure and also allows for measurement of fluid flow through the samples. Fractures develop, providing high-permeability flow conduits thus facilitating unconventional resource production without water. The integrated experimental-analysis-observational approach facilitates the characterization of electro-induced fractures and their impact upon fluid flow for unconventional reservoir development. This experimental system allows for fundamental understandings of the fracture process, production sustainability, and optimal electrical wave forms to minimize energy requirements and improve system optimization.

Background/Motivation

Shell Oil Co (Electrofracturing formations, US 20130255936 A1) and Husky Oil Operations Co. (Method of Subsurface Reservoir Fracturing using Electromagnetic Pulse Energy, US 2015/0192005) each discuss ways to initiate and propagate fractures in a hydrocarbon reservoir. This stimulation of the initially low permeability reservoir is to be accomplished by supplying high voltage electrical pulses to the formation. "Electrofracturing" occurs through two general processes (Cho et al, 2006): 1) electrohydraulic shock and 2) internal breakdown inside bulk solid dielectrics. In the first process, electrical current passing through brackish or salty water found naturally in the formation generates a shock wave of sufficient magnitude to crush/fail the rock as the wave travels through it (consider a very rapid increase in pore water pressure sufficiently great to overcome in situ stresses and rock strength). In the second process, the electric current flows through the rock preferentially along mineral interfaces; tensile and branching cracks are induced at the boundary interfaces either by heating and differential expansion, or by a shock wave induced by the electrical impulse itself.

We developed a laboratory based experimental system to evaluate this potentially game changing technology: water-free shale stimulation. We have coupled deformation and gas flow during high-voltage pulse application at elevated pressure (to 70 MPa).

The success of elctrofracturing will help further secure the nation's supply of clean energy of natural gas, a goal of the Department of Energy and, perhaps more importantly, provide important information to fielding this water free fracturing technology. In the US, water minimization is important for resource and environmental conservation. Abroad, in emerging nations, this technology may enable resource stimulation in water-barren environments. Such countries can then use cleaner/greener resources to generate electrical energy. This research will assist in setting the U.S. at the forefront of a new environmentally friendly shale gas production technology through waterless stimulation of natural gas reservoirs.

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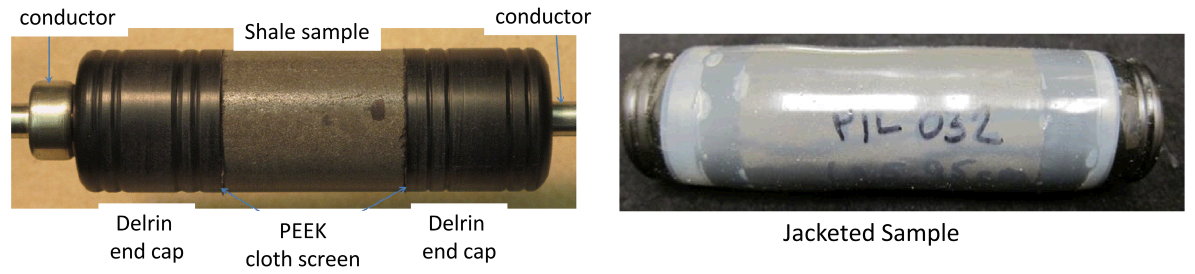
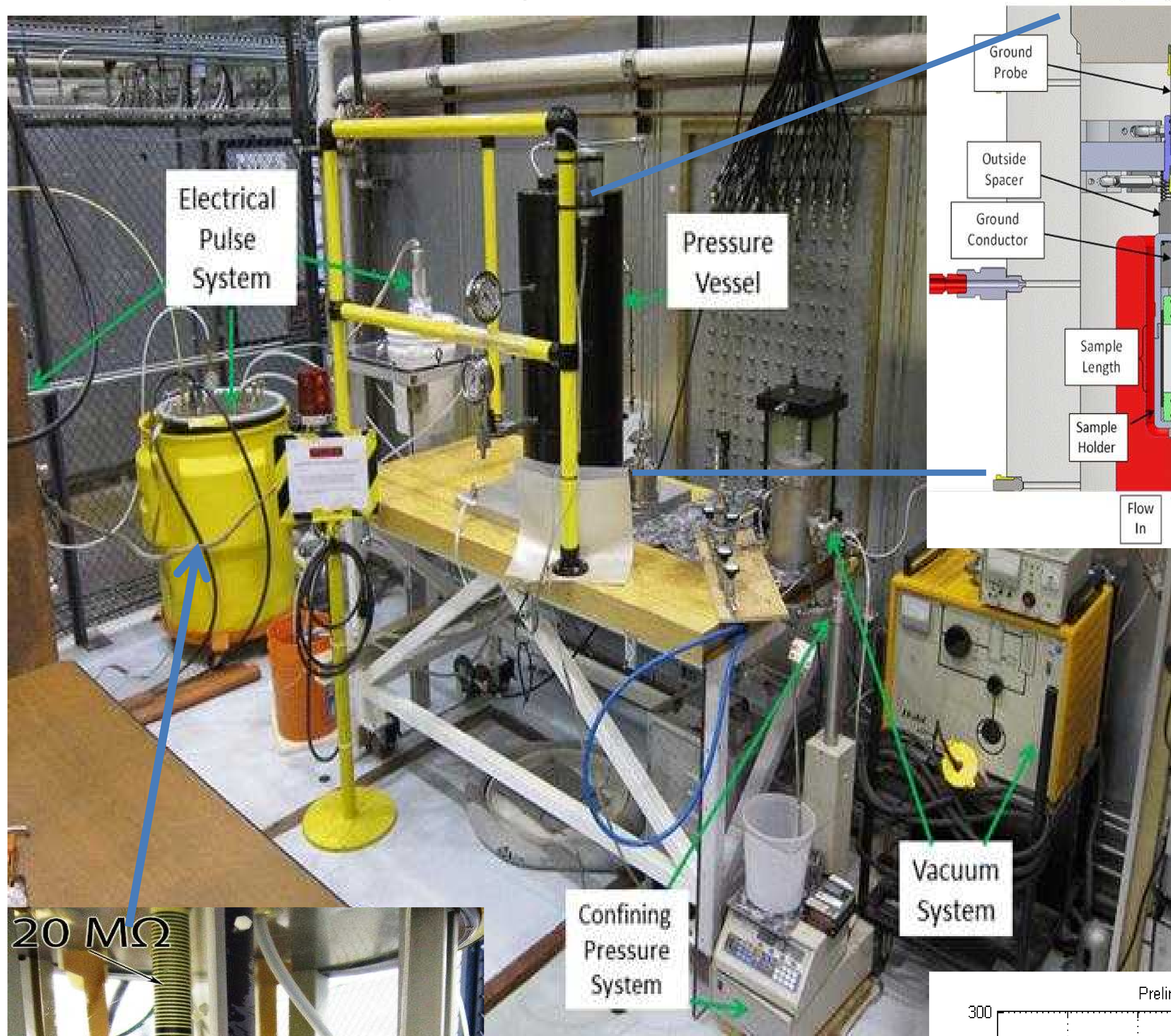
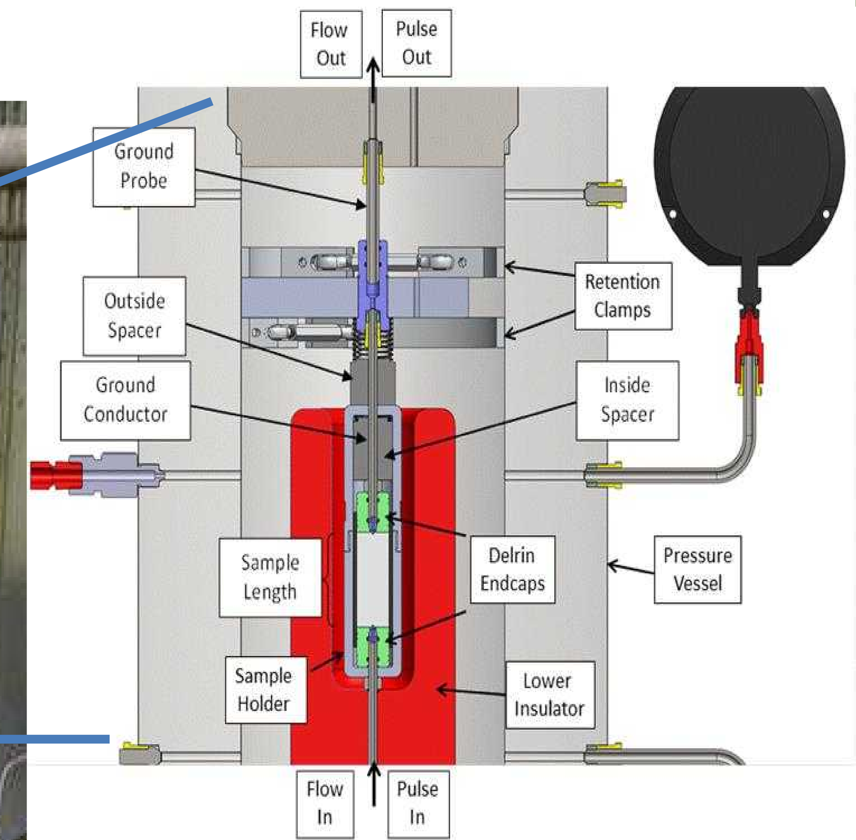
Test System Components

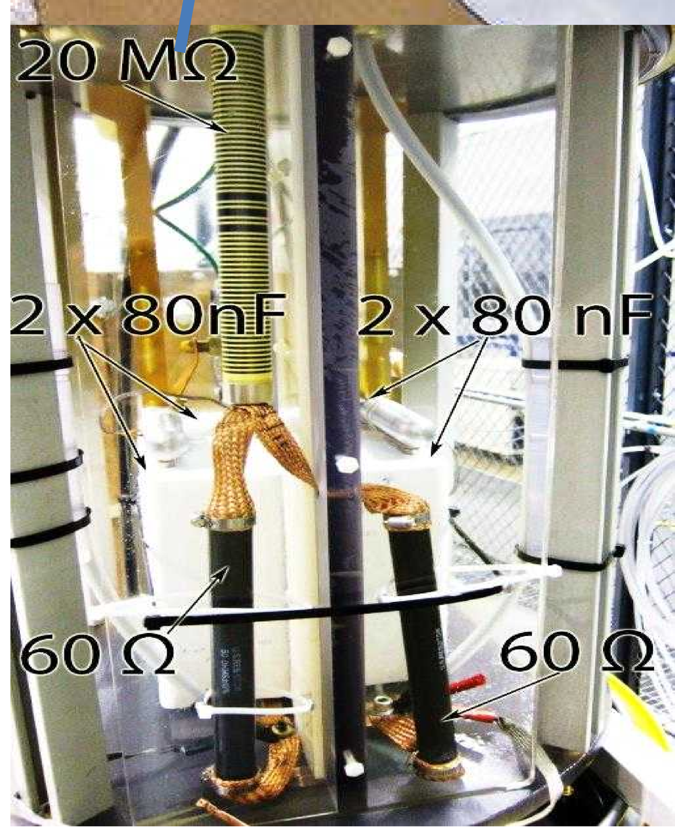


Sample configuration

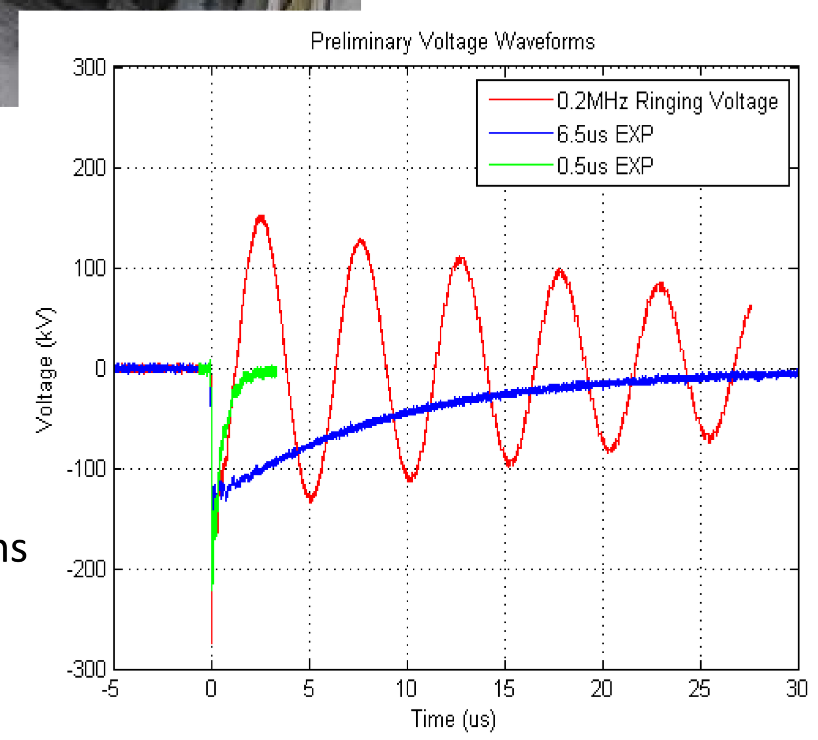
Electrode/ high pressure flow through







Pulsed power generator internal components:
-pulse shaping resistors
-dump resistor
-capacitors.



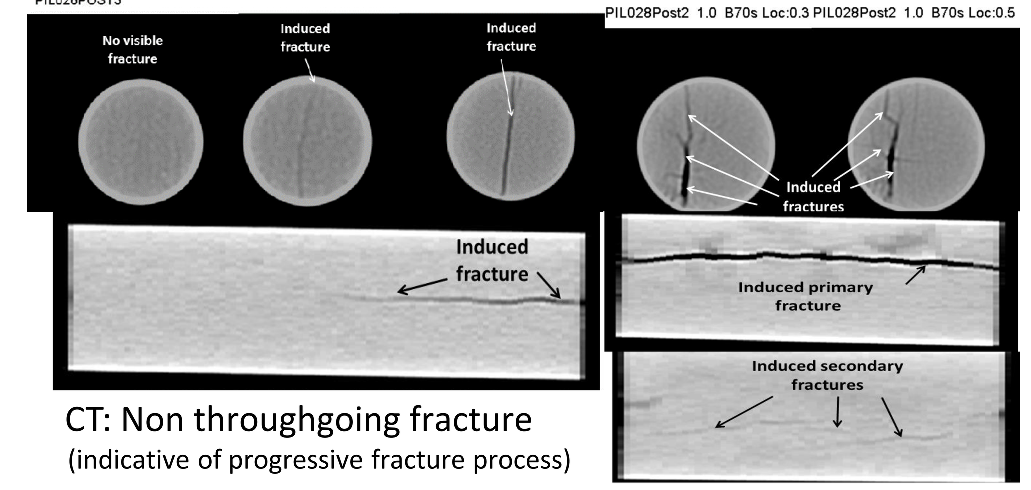
Pulse waveforms considered

The test system consists of a 70 MPa pressure vessel fitted with hardware to hold samples up to ~15cm in length. The electrical/pressure fitting at the vessel base is composed of Delrin, a high strength polymer. Diala AX fluid is used a the confining medium. The pulsed power generator was designed and built in house from standard components. Moving internal electrically insulating seals are made from a combination of standard O-rings, Delrin end pieces, and high pressure tubing fitted with flow-through ports. Gas flow is measured using a helium mass spectrometer and standard mass flow meters. Confined samples are subjected to 6.5 µs full width at half maximum exponential voltage pulses from 80 to 200 kV (~300A).

Permeability: 5 to 8 order-of-magnitude increase

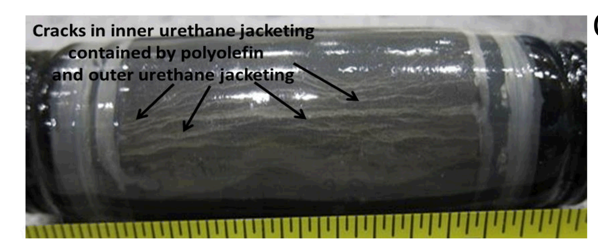
Sample	Date	Confining Pressure (psi)	L (cm)	D (in)	P_i (psig)	P_o (psia)	Q (cc/s)	K (m^2)	K (nD)	Description
PIL-028	8/7	3000	6	1	49.9	1.0E-04	5.00E-08	1.3E-22	0.1	Start
					50	1.0E-04	6.00E-07	1.5E-21	1.5	Overnight
					50	1.0E-04	7.00E-07	1.8E-21	1.7	after shot5
					50	1.0E-04	1.00E-06	2.5E-21	2.5	after shot10
					50	1.0E-04	1.60E-06	4.0E-21	4.0	Overnight
					15.64	1.2E+01	**2.83E+01**	**6.4E-13**	**4.4E+08**	Break
PIL-029	8/22	8500	6	1	50	1.0E-04	7.90E-08	2.0E-22	0.2	Initial Overnight
					14.59	1.2E+01	**7.73E+00**	**1.9E-13**	**1.3E+08**	Break
					14.59	1.2E+01	**7.47E+00**	**1.9E-13**	**1.3E+08**	Break - Overnight
PIL-026	8/30	8500	9	1	50	1.0E-04	2.47E-10	9.4E-25	0.0	Initial Overnight
					50	1.0E-04	5.63E-10	2.1E-24	0.0	105 shots
PIL-030	10/1	3000	5.95	1	50	1.0E-04	3.12E-04	7.8E-19	782.0	Initial Overnight
					15	1.2E+01	**1.00E+00**	**2.4E-14**	**1.6E+07**	Break
PIL-032	10/2	8500	5.95	1	50	1.0E-04	2.96E-04	7.4E-19	742.4	Initial Overnight
					15	1.2E+01	1.47E-02	**3.5E-16**	**2.4E+05**	Break
PIL-038	10/9	8500	3.1	1	49.9	1.0E-04	1.20E-04	1.6E-19	155.2	Overnight
					15	1.2E+01	9.67E-01	**1.2E-14**	**8.2E+06**	Sample broke on first shot at 160 kV
PIL-025	10/10	8500	9.2	1	49.9	1.0E-04	3.93E-06	1.5E-20	1.5E+01	Overnight
					15	1.2E+01	2.97E+00	**1.1E-13**	**7.5E+07**	Sample broke on first shot at 160 kV
Blank	8/5	3000	3	1	49.9	1.0E-04	7.00E-10	8.9E-25	0.0	Overnight (made from aluminum)

Microstructural Observations



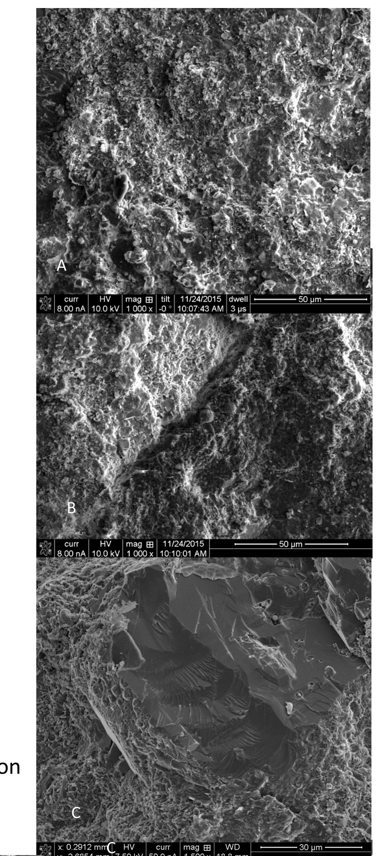
CT: Non throughgoing fracture
(indicative of progressive fracture process)

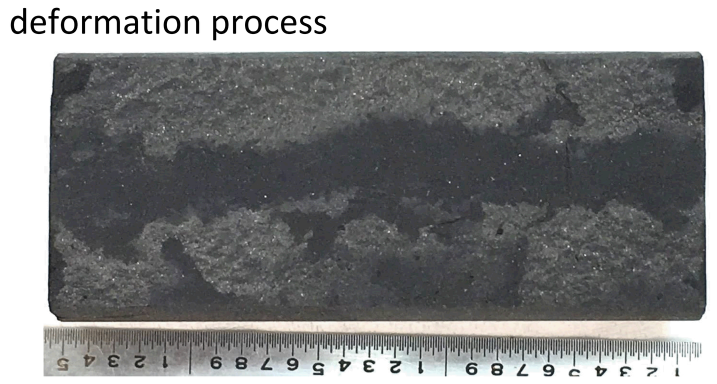
CT: Throughgoing fractures



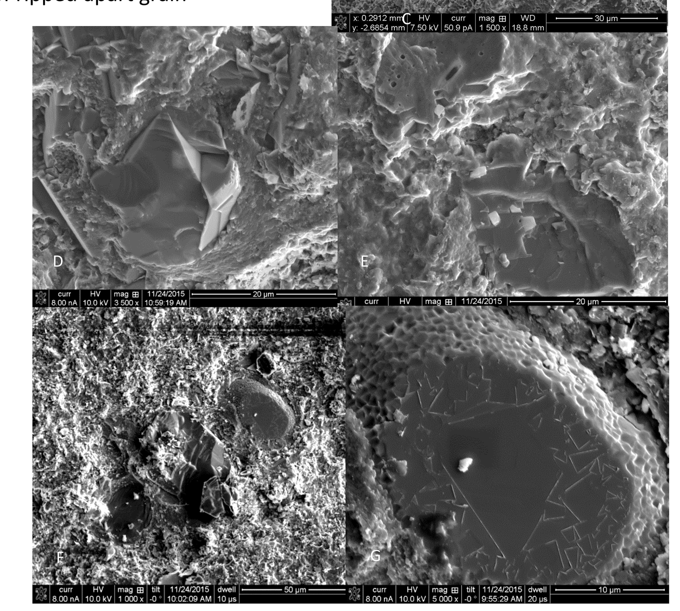
Fracturing of the jacket material from the inside out implies high internal pore pressures were generated as part of deformation process

SEM images
A, B: fracture surface
C, D, E: fractured grains, ripped apart in tension
F, G: fracture surface; internal deformation of ripped apart grain





Fracture surface, reflected light.



SEM photos by M.M. Mills

Summary

A laboratory based experimental system was developed to study the electrofracturing process at relevant in situ reservoir conditions The test system can accommodate both deformation and gas flow during high voltage pulse applications at elevated pressures (to 70 MPa). Twelve samples were tested using 6.5 µs full width at half maximum exponential voltage pulses from 80 to 200 kV. Exponential decay loading was shown to fracture shale at pressure, producing a 5 to 8 order-of-magnitude increase in permeability (initiating in the nD range) with significant fracturing. The resultant permeability may be sustainable.

The preponderance of fractures (using CT and SEM) are bedding parallel, and appear to be tensile in nature. The fracture process is progressive (samples fractured a portion of length). The samples appear to have fractured by internal gas pressurization (suggesting rapid increase in pore pressure).

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