ExxonMobil's Electrofrac Process for *In Situ* Oil Shale Conversion*

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Abstract

ExxonMobil's Electrofrac process is an energy efficient method for converting oil shale to producible oil and gas. The method heats the oil shale *in situ* by hydraulically fracturing the oil shale and filling the fracture with electrically conductive material, forming a heating element. The shale oil and gas are produced by conventional methods.

Electrofrac research has included small-scale experiments, numerical modeling, and resource description work addressing critical technical issues. This presentation provides an overview of the research, highlights of which are:

(1) Laboratory experiments demonstrating the following: (1a) Hydrocarbons will be expelled from heated oil shale even under in situ stress, (1b) Electrical continuity of the fracture heating element is unaffected by kerogen conversion, and (1c) Calcined petroleum coke is a suitable conductive material for use as the fracture heating element.

(2) Modeling including the following: (2a) A Piceance Basin geomechanical model that shows most of the Green River oil shale is in a stress state favoring vertical, rather than horizontal, fractures, (2b) Heat conduction models that show several fracture designs can deliver heat effectively, and (2c) A phase behavior model that shows volume expansion is a large potential drive mechanism. *In situ* oil shale can expand by 70% upon kerogen conversion.

(3) Resource description work indicating that Piceance Basin oil shales are sufficiently thick and rich for commercial development by the Electrofrac method.

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ExxonMobil's Electrofrac™ Process for *In Situ* Oil Shale Conversion

William A. Symington, David L. Olgaard,
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AAPG Annual Convention & Exhibition

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Electrofrac

Oil Shale Conversion via Electrically Conductive Fractures

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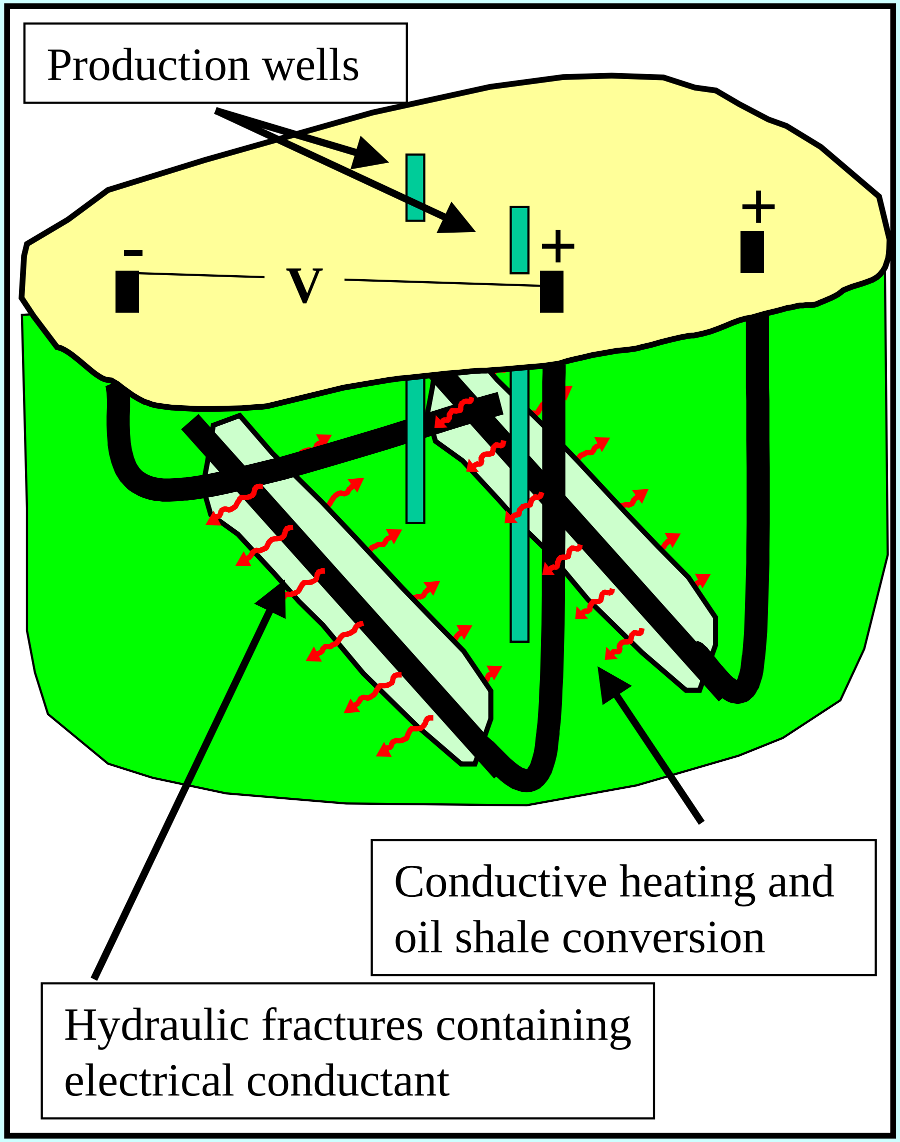
- **Early screening research indicated:**
  - ***In situ* methods preferred.**
  - **Heat conduction is the best way to "reach into" oil shale.**
  - **Linear conduction from a planar heat source is more effective than radial conduction from a wellbore.**
- **Electrofrac concept is applicable with either vertical or horizontal fractures.**
- **Conductant electrical resistivity:**
  - **high enough for resistive heating.**
  - **low enough to conduct sufficient current.**
- **Electrofrac research has focused on critical technical issues:**
  - **Identification of conductant.**
  - **Maintaining electrical continuity.**
  - **Expulsion under *in situ* stress.**
  - **Completion strategy for effective heating.**



Electrofrac Laboratory Research has Focused on Critical Technical Issues

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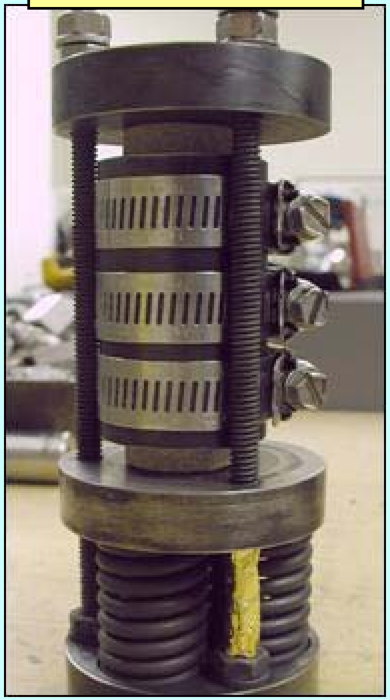
Core-plug-scale experiments demonstrate:

- Calcined coke is a candidate conductant.
- Electrical continuity is not disrupted by kerogen conversion.
- Hydrocarbon expulsion under *in situ* stress.

Modeling indicates:

- Volume expansion is a large potential drive mechanism.
- Fractures will generally be vertical.
- Longitudinal fractures heat effectively.

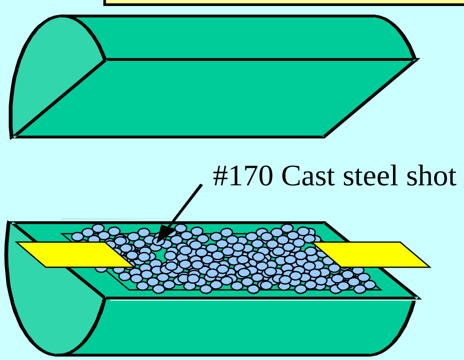
Hydrocarbons Expelled under Stress



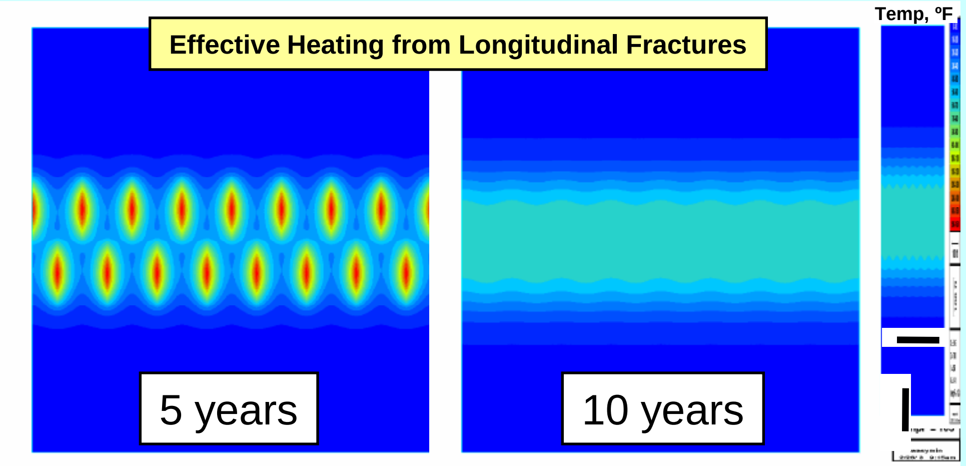
20/40 Mesh Proppant

Calcined Coke

Electrical Continuity Undisrupted by Kerogen Conversion



Effective Heating from Longitudinal Fractures



Identification of Conductant

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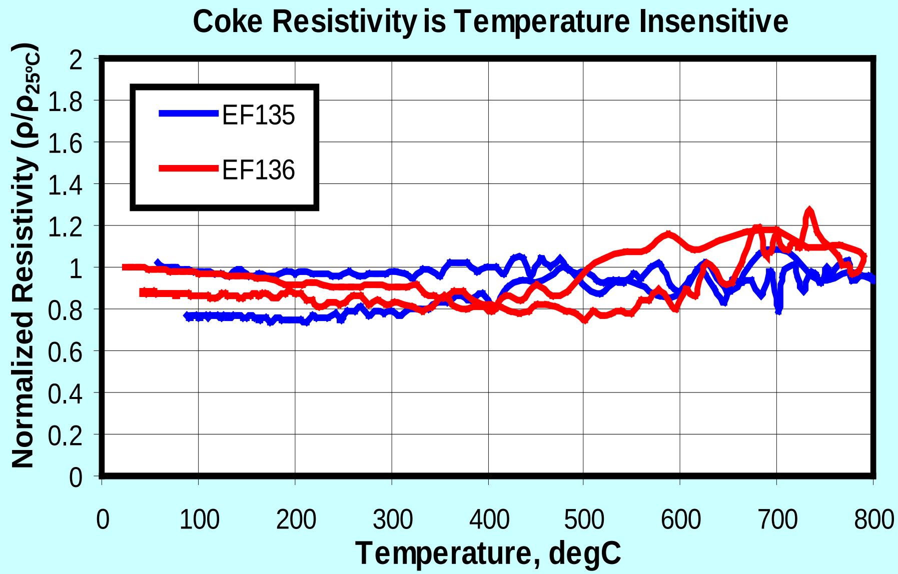
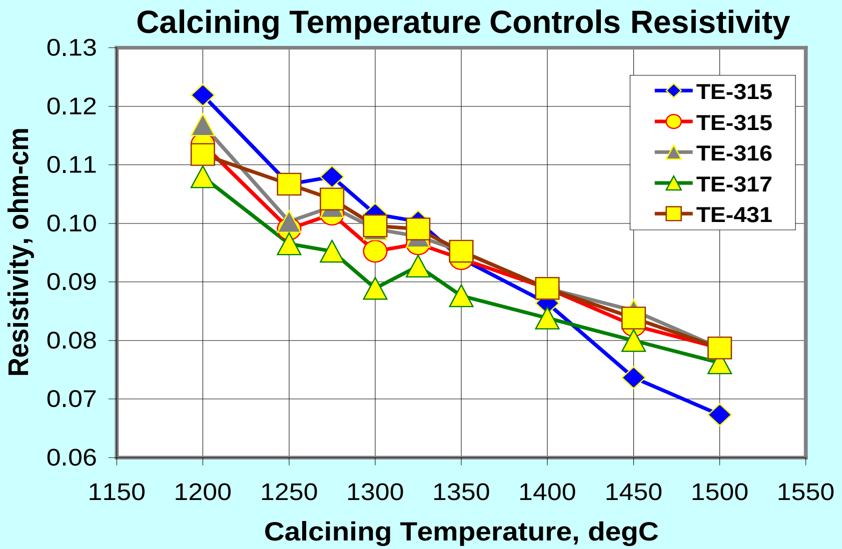
Calcined Petroleum Coke is a Candidate Electrofrac Conductant

- Physical properties (density, particle size) similar to fracture proppants.
- Electrical resistivity in desired range and temperature-insensitive. Resisitivity should be controllable by calcining process.
- Chemical stability up to calcining temperature.
- Readily available. Current uses are -
  - Carbon anodes for aluminum smelting.
  - Anode beds for cathodic protection.
  - Packing for industrial electrical grounding.



20/40 Mesh Frac Proppant

Calcined Coke



Data from Hardin et al, 1992

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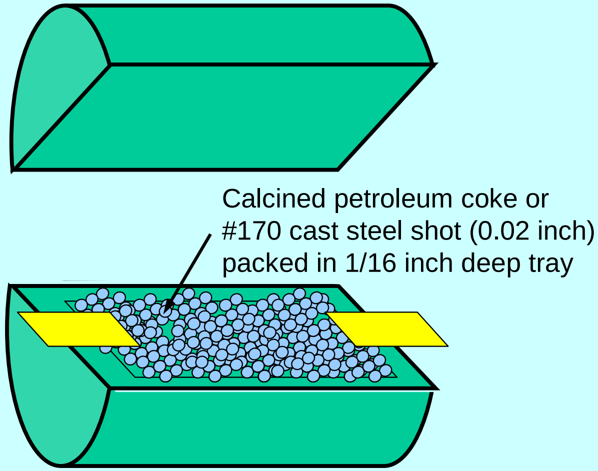
Particle Embedment Does Not Disrupt Continuity in Core-Scale Experiments



- Stress applied with hose clamps to achieve electrical continuity.
- Sample heated externally to 360ºC for 24 hours – 90% uniform conversion achieved.
- Although embedment occurred to a minor degree, electrical continuity was not disrupted.

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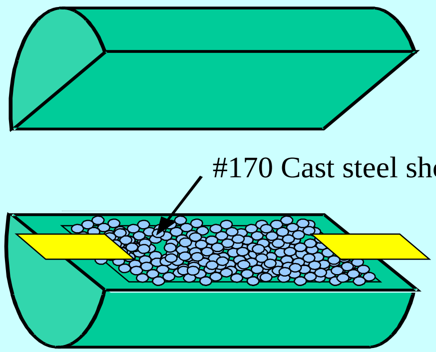
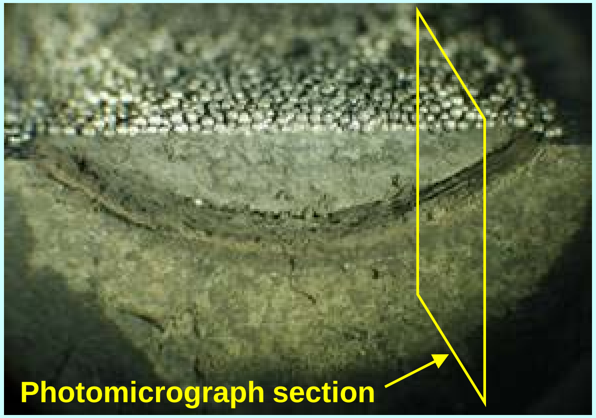
Simulated Electrofrac Heating Circuit Undisturbed by Kerogen Conversion

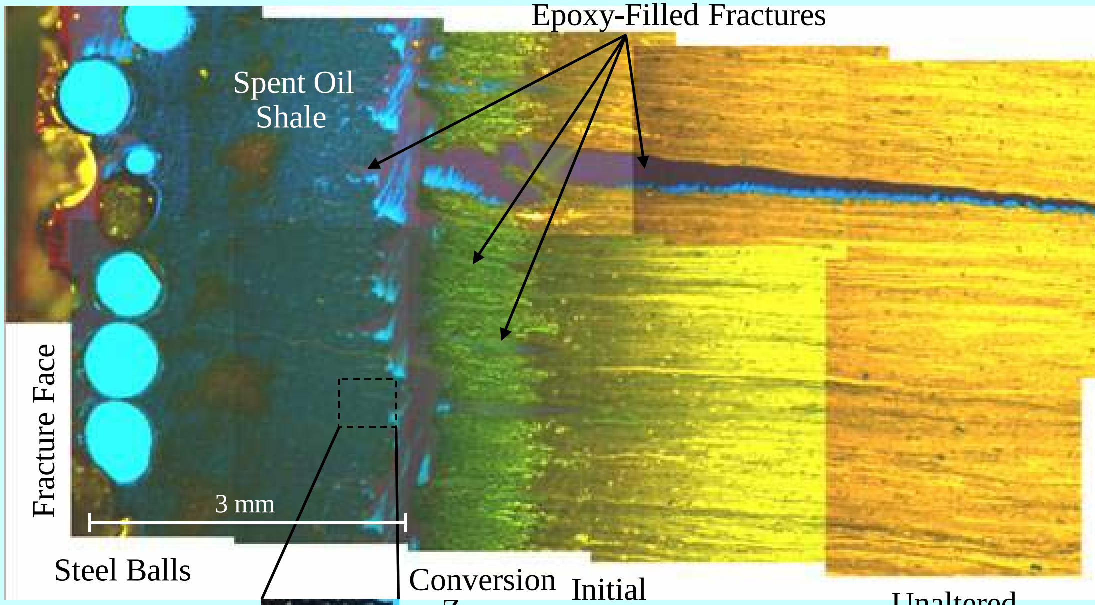




Experiment Summary

- Heated with 20 amps for 5 hours (~60 W). Circuit not disrupted by rock alteration.
- Internal measured temperature reached 268ºC. Estimated fracture temperature of 350-400ºC.
- Thermal expansion caused fractures in the sample.
- Recovered 0.15 mL of oil.

Photomicrograph under Fluorescent Light



Spent Oil Shale Thin Section Showing Porosity (blue)

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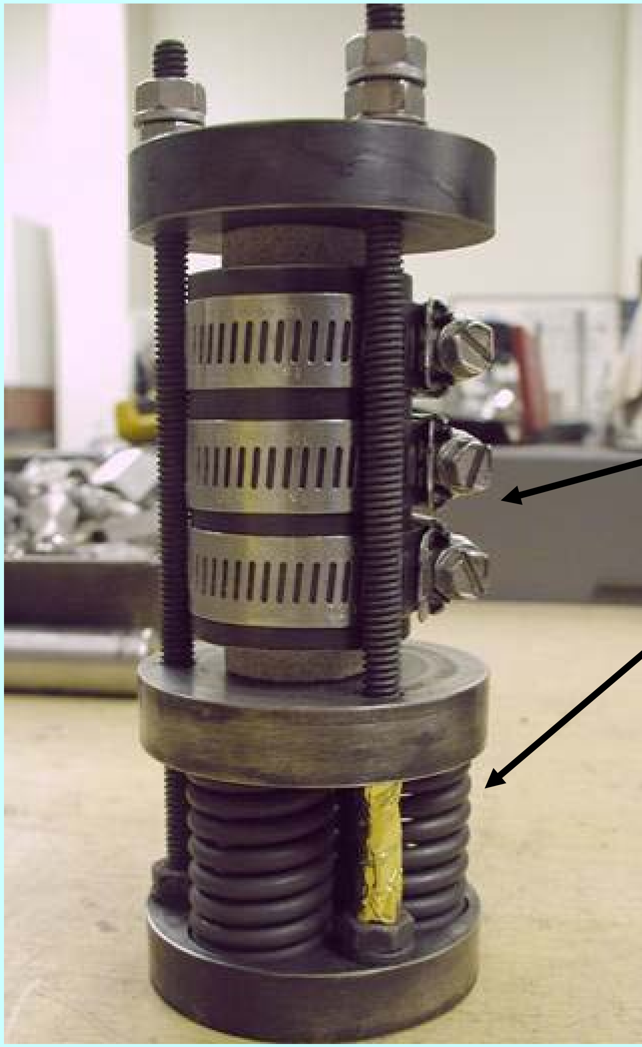
Experiments Demonstrate Expulsion of Hydrocarbons Under Stress



- Stress is applied in axial direction, strain is inhibited in lateral directions.
- Experiments under stress recovered 21 to 34 gal/ton from 42 gal/ton samples.

Oil shale inside Berea cylinder - jacketed and clamped

High temperature (Inconel) springs provide axial load. Gold foil records maximum spring deflection.

Expulsion Under In Situ Stress

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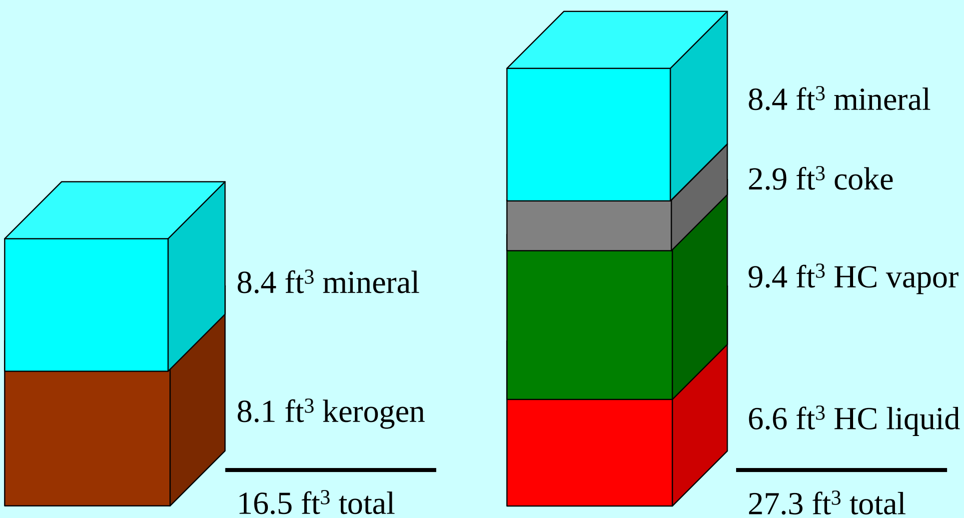
Volume Expansion Provides a Large Potential Drive Mechanism

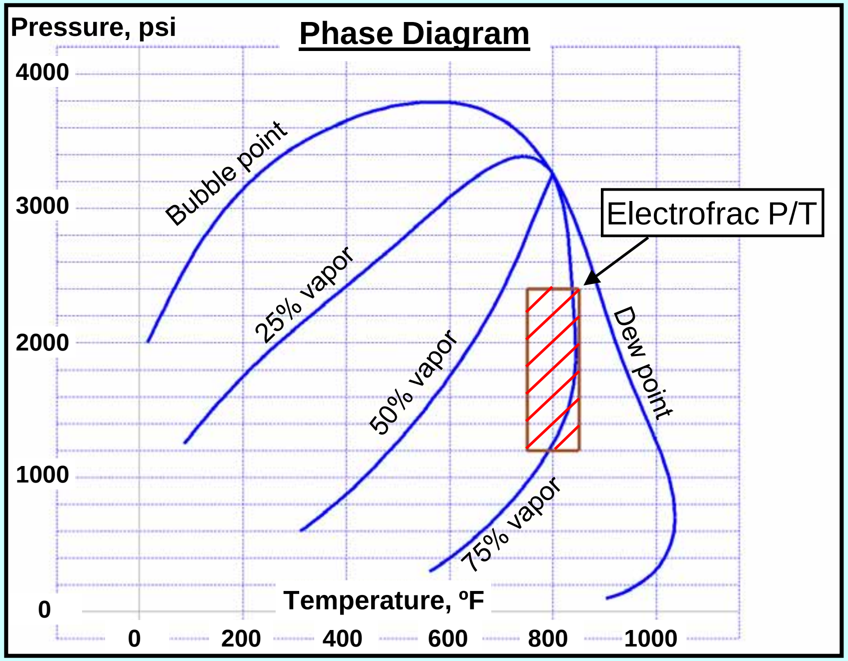
- Product compositions derived from MSSV (micro-sealed spherical vessel) pyrolysis experiments.
- Equation-of-state model used to calculate expected density and phases at typical Electrofrac conditions.

1 Ton of Green River Oil Shale (22% TOC, 42 gal/ton)



Before Conversion

After Conversion @ 2400 psi, 750°F (without liquid cracking to gas)



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Completion Strategy for Effective Heating

In Piceance Basin, Electrofrac Heating Fractures will be Dominantly Vertical

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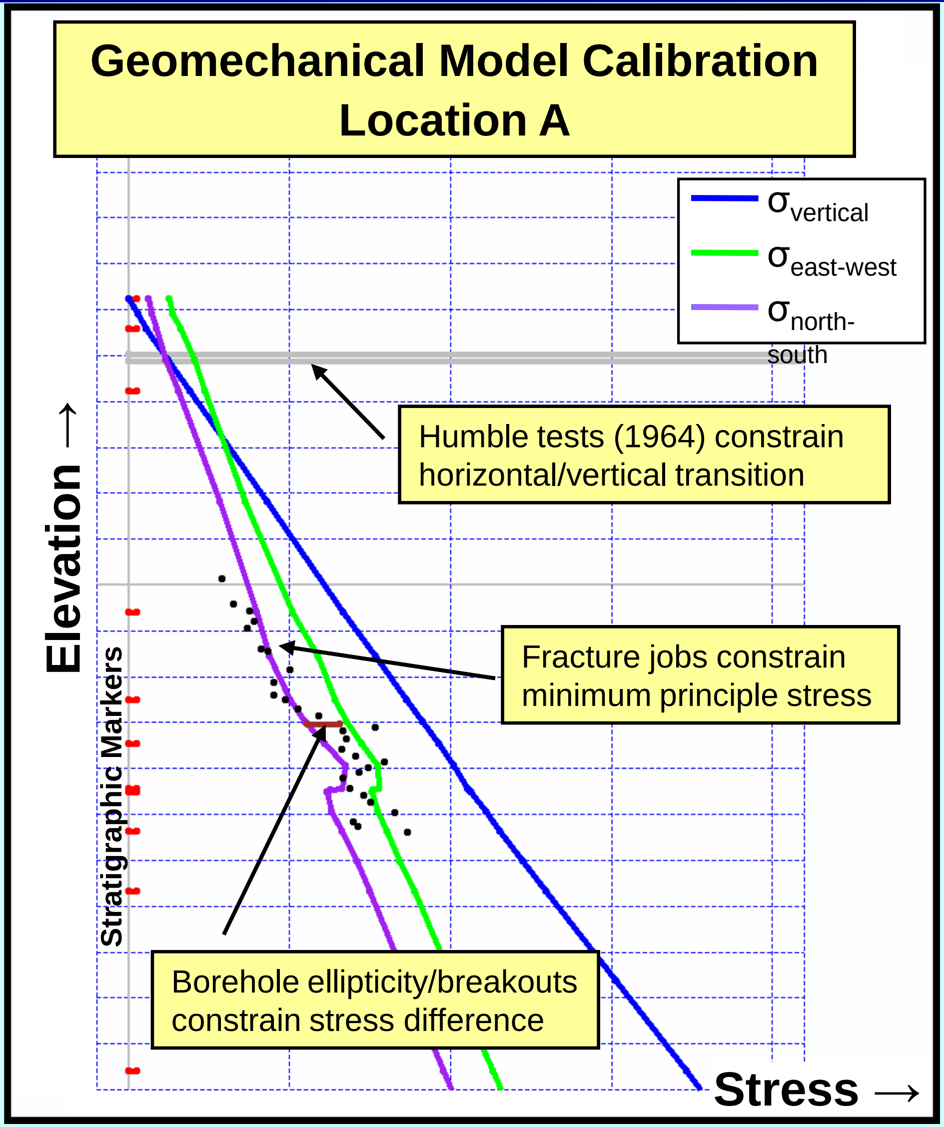

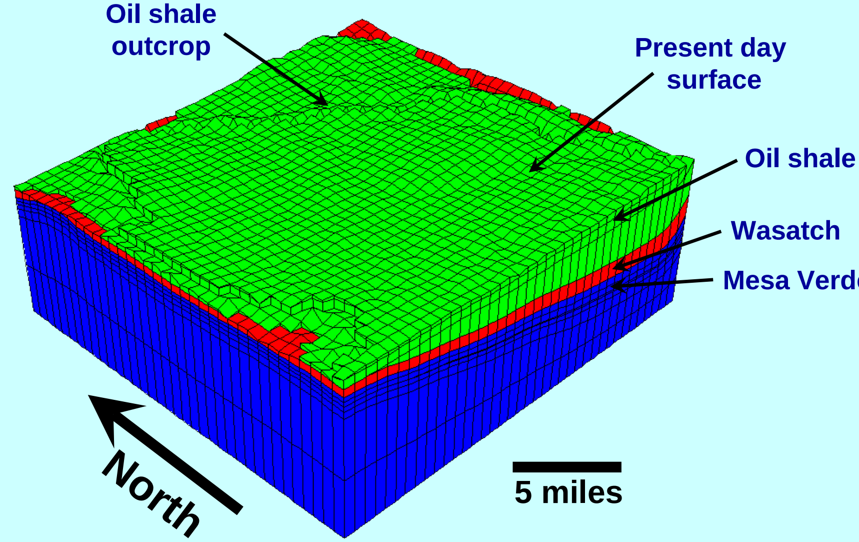

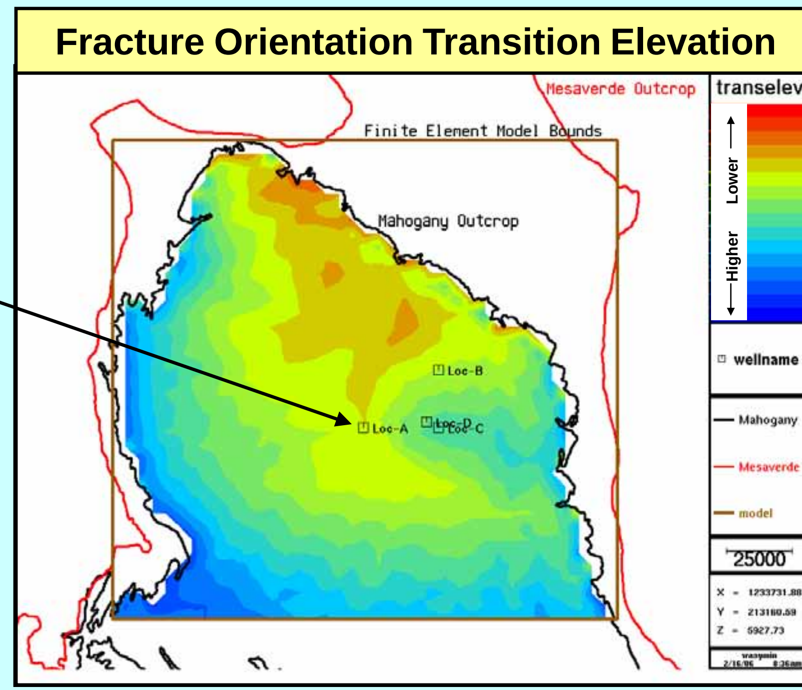

Symington, W. A. and Yale, D. P, 2006, ARMA GoldenRocks Conference

Preferred Process Geometry Relies on Vertical Electrofrac Heating Fractures

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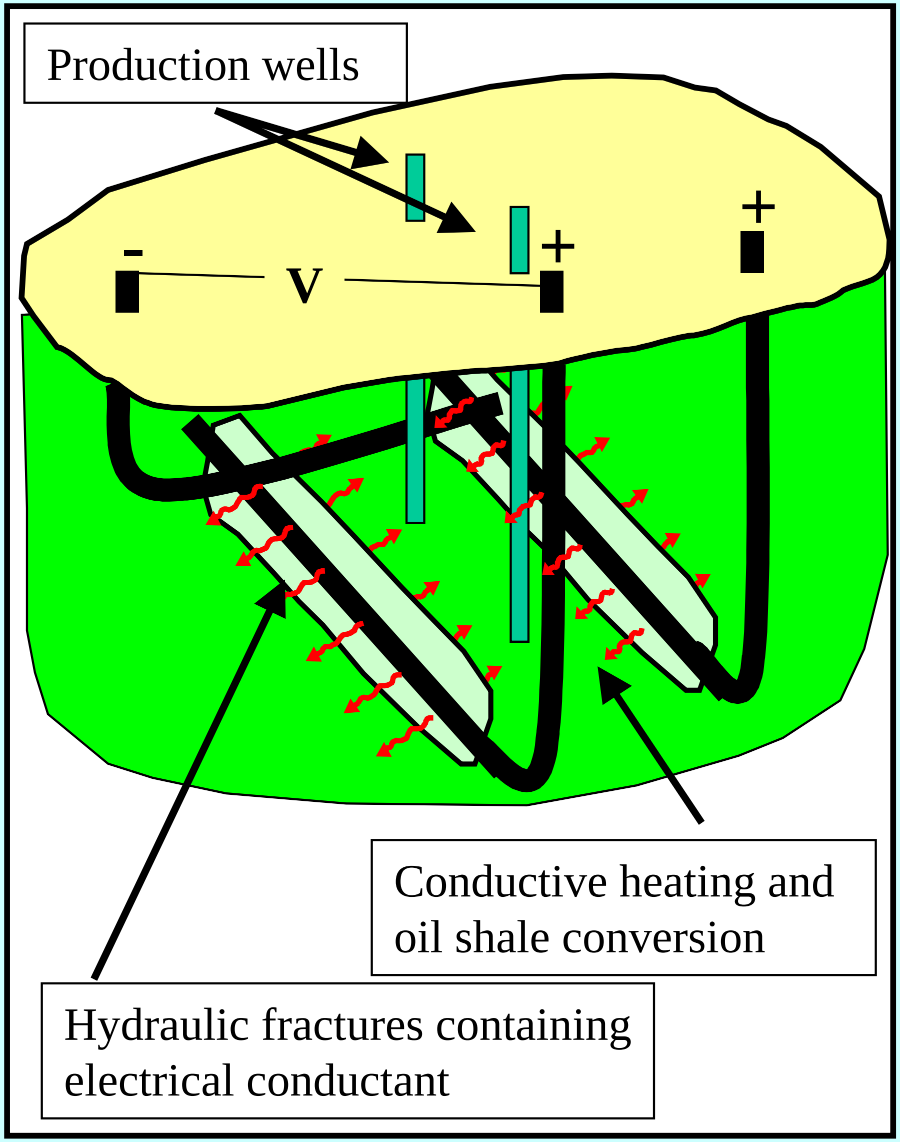
- Heating wells drilled horizontally, perpendicular to direction of least principal *in situ* stress.
- Vertical longitudinal fractures filled with electrically conducting material.
- Electrical conduction from the heel to the toe of heating wells.
- For reasonably spaced fractures, induced stresses should not alter the least principal *in situ* stress direction.
- Multiple layers of heating wells may be stacked for increased heating efficiency.



Completion Strategy for Effective Heating

Modeling Optimizes Heating Efficiency

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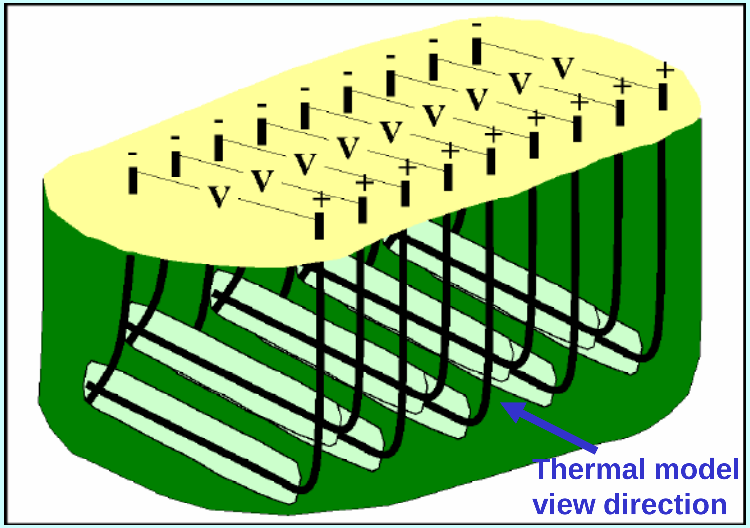
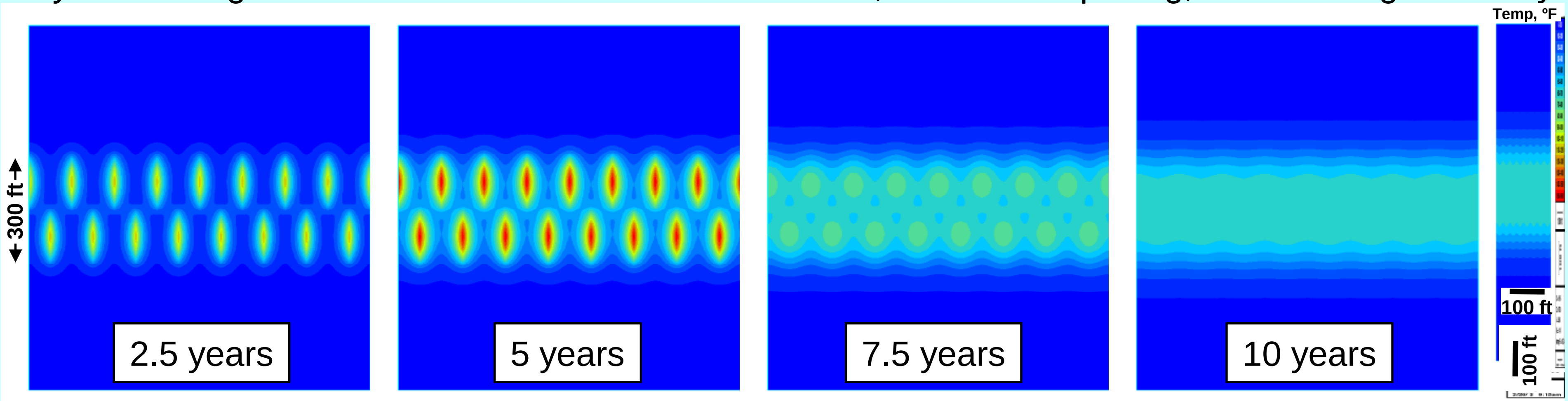
Process Schematic



Simulation Case Selected as "Typical" – 150 foot fracture height,
5-year heating sufficient to convert 325 feet of oil shale, 120-ft frac spacing, 74% heating efficiency



Electrofrac

Oil Shale Conversion via Electrically Conductive Fractures

ExxonMobil's Electrofrac research has focused on critical technical issues. Research highlights include:

- Laboratory experiments demonstrating –
  - Calcined petroleum coke is a suitable Electrofrac conductant.
  - Electrical continuity is unaffected by kerogen conversion.
  - Hydrocarbons will be expelled from heated oil shale even under *in situ* stress.
- Modeling including the following –
  - A phase behavior model showing volume expansion is a large potential drive mechanism for expulsion. *In situ* oil shale can expand by 65% upon kerogen conversion.
  - A Piceance Basin geomechanical model showing the stress state of the Green River oil shale favors vertical fractures.
  - Heat conduction models showing that several fracture designs can deliver heat effectively. A "typical" case requires one Electrofrac heating well every 1.5 acres.

References

Hardin, C.D., 1992, Considerations in the application of microprocessor based systems as safety layers in a chemical/petrochemical plant: National Petroleum Refiners, v. 136.

Symington, W.A., and D. Yale, 2006, Interpolation/extrapolation of measured in situ earth stresses; an example from the Piceance Basin in western Colorado: *in* The 41st U.S. Symposium on Rock Mechanics (USRMS), Golden Rocks 2006, p. 12.