Organic-Rich Rock Conversion Approach (ORRCA)

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Summary

The vast majority (more than 90%) of potential hydrocarbon reserves exists not as oil and gas in reservoirs but as kerogen in fine-grained, impermeable, organic-rich rocks (ORR). The ORRCA concept provides a methodology to generate and produce large volumes of hydrocarbons directly from these organic-rich rocks. The process uses *in situ* combustion in a reservoir to heat overlying organic-rich top seals and transform kerogen to hydrocarbons. The generated hydrocarbons are expelled from the organic-rich rock and produced. Economic advantages lie in application to depleted oil fields, where wellbores and facilities are already in place and where the fuel required for *in situ* combustion exists as residual or uneconomic oil.

A multidisciplinary research program addressed three major tasks: 1) characterization of potential prospects, 2) technical assessment of the heat transfer and generation of hydrocarbons, and 3) economic analysis. This poster focuses primarily on the technical assessment of the method. Evaluation of organic-rich rocks showed that they rival good oil reservoirs if the organic matter within them can be converted to producible hydrocarbons. Reservoir simulations were used to model the *in situ* combustion process. Simulation results were compared to temperatures measured in field combustion projects. Thermal modeling showed that temperatures generated by *in situ* combustion in an underlying reservoir can provide sufficient heat for kerogen conversion several tens of feet from the reservoir/ORR interface.

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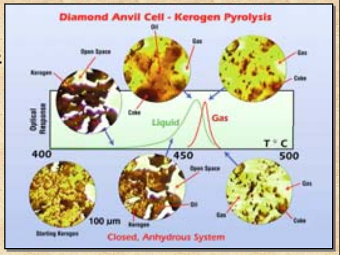
1990's Oil Shale Research

Green River Kerogen Pyrolysis Experiments

- Samples consist of kerogen concentrates.
- Diamond anvil cell fits on a microscope stage.
- Maturation and hydrocarbon generation monitored by real time video imaging.

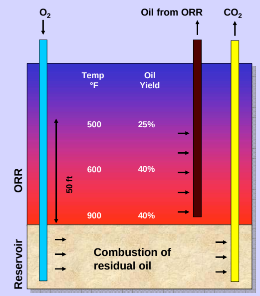


Process Screening Study

- **Goal:** An innovative approach for producing oil and gas from organic-rich rocks such as oil shale.
- **Result:** Researched 30+ potential technologies.
  - *In situ* conversion is preferable for oil shale.
  - Best way to "reach into" the shale to convert kerogen to oil and gas is by heat conduction.
  - Linear heat conduction from a planar source is superior to radial heat conduction from wellbores, as it leads to lower well density.

Field Study of Exshaw Shale

The ORRCA Concept

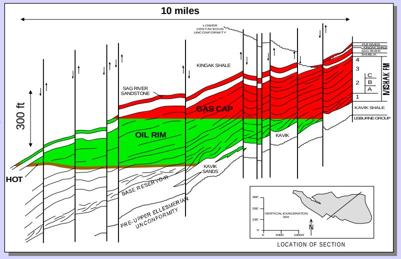


- Top seals of many oil reservoirs are immature organic-rich rocks.
- *In situ* combustion of residual oil can generate heat adjacent to the top seal.
- Heat conducted into the top seal can artificially mature the kerogen.
- *In situ* combustion and production are facilitated by existing infrastructure.

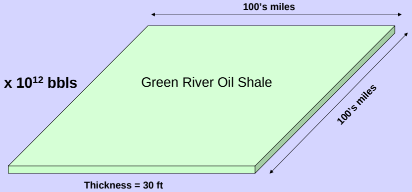
Enormous Hydrocarbon Potential in Organic-Rich Rocks

Prudhoe Bay Reservoir

OOIP = 22 x 10^9 bbls

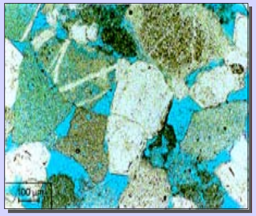


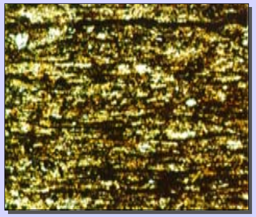
$OOIP_{equiv}$ = 8 x 10^{12} bbls



Comparable Potential Reserves per Unit Volume

Prudhoe Bay Reservoir	Pebble Shale Source Rock
1240 bbl/acre-ft	930 bbl/acre-ft

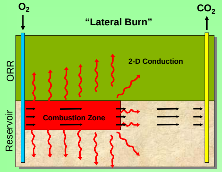




Prudhoe Bay Reservoir	Pebble Shale Source Rock
Average Porosity ≈ 20%	Average Porosity ≈ 10%
Average Sw ≈ 20 %	Average TOC ≈ 6 wt %
Thickness ≈ 300 ft	Thickness ≈ 75 ft
Permeability ≈ 1-3 Darcy	Permeability ≈ 10^{-8} Darcy

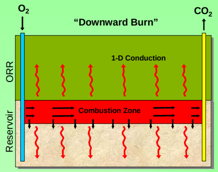
Analytical Modeling

Thermal Conduction Modeling of ORRCA Process



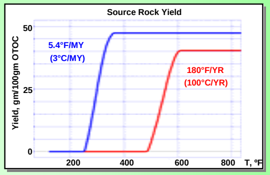
Model Input Parameters:

- Reservoir thickness
- Organic-rich-rock thickness
- Burn-zone thickness
- Injector-to-producer distance
- Original reservoir temperature
- Adiabatic burn temperature
- Rate of burn progression
- Thermal diffusivity
- Time to end of calculations

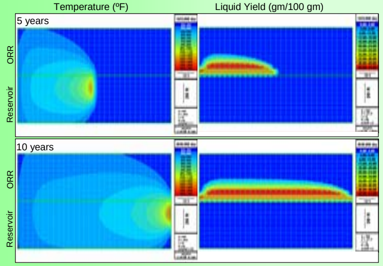


Organic-Rich Rock Generation Model

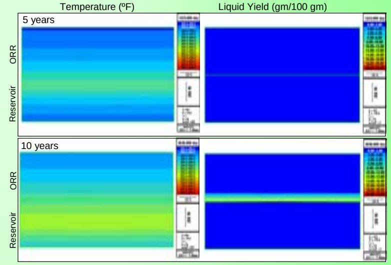
- Marine source rocks
- Simple chemistry and expulsion model
  - Kerogen ⇒ Oil + Gas + Coke
  - Oil ⇒ Gas + Coke
- First order reaction kinetics
- Oil retained in source rock is available to crack to gas
- High maturity gas included in model



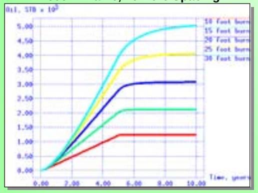
10-Year Lateral Burn, 25-Feet Thick, 40-Acre Spacing, 1600°F Adiabatic Burn Temperature



10-Year Downward Burn, 25-Feet Thick, 40-Acre Spacing, 1600°F Adiabatic Burn Temperature



Oil Generation History – 5 Year Lateral Burn
1600°F Flame, 40 Acre Spacing



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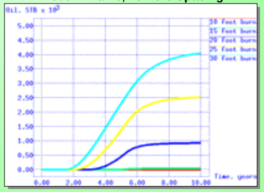
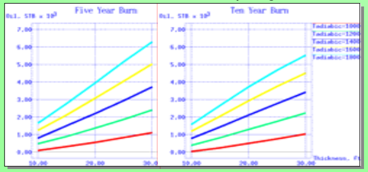
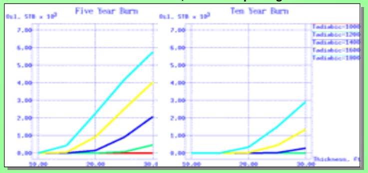


Cumulative Oil Generated in 10 Years
Lateral Burn, 40 Acre Spacing



Cumulative Oil Generated in 10 Years
Downward Burn, 40 Acre Spacing



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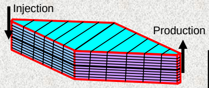
Numerical Simulation

Example Simulation Case
"Typical Waterflooded Oil Reservoir"

Reservoir Properties
- 5000 ft
- 155°F
- 2300 psi
- 25% porosity
- 100 mD permeability
- k_v/k_h = 0.3
- 40% oil saturation



Model Properties
- 2-D rhombohedral cross-section
- 20-acre pattern
- Inject 1 Mscfd O_2 / pattern
- 4 HC pseudocomponents
- Coke and gas combustion

ORRCA Simulation Methodology
- Model combustion and conduction with STARS®
- Use ORR thermal history to model ORR generation

Range of Variables Tested (approximately 400 simulations)

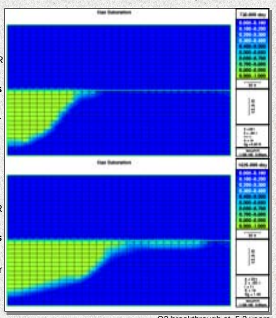
Reservoir Properties
- Depth: 3000-9000 ft
  - Temperature: 100-220 °F
  - Pressure: 500-4000 psi
- Oil saturation: 30-50%
- Structure: 0-15° dip, up or down
- Heterogeneity: 30-300 mD
- Average permeability: 100 mD
- Vertical perm: kv/kh = 0.01 - 0.4
- Thickness: 3-50 ft
- Thermal conductivity: 15-48 Btu/d-ft-°F

Injectant Properties
- Oxygen vs. air
- Rate: 1 - 2.4 Mscfd O2 / pattern

Fluid Properties
- Fuel: Gas, oil, coke
- Kinetics matched to lab data
- Pseudocomponents: 2 - 5 hydrocarbon components
- K values varied by factor of 10

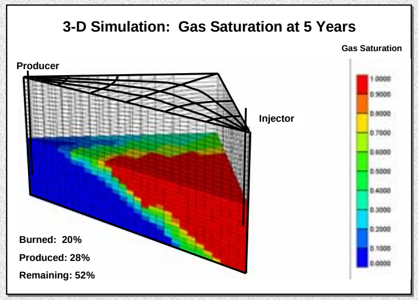
Model Properties
- Coordinate systems: cartesian, radial, rhombus
- Grid block size: z thickness = 1 - 3 ft
- 20- or 40-acre pattern
- Mostly 2D, some 3D

Gas Saturation - 5000 Feet, So = 40%

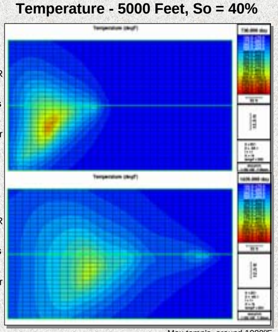


O2 breakthrough at 5.2 years

3-D Simulation: Gas Saturation at 5 Years



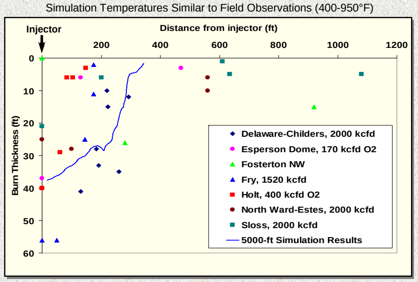
Temperature - 5000 Feet, So = 40%



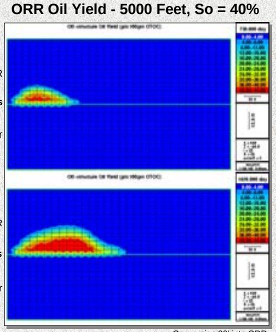
Max temp's. around 1000°F

Comparison to Field Burn Thickness and Temperatures

Burn Zone Thins with Distance from Injector
Simulation Temperatures Similar to Field Observations (400-950°F)

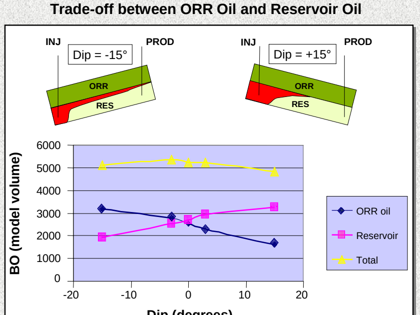


ORR Oil Yield - 5000 Feet, So = 40%



Conversion 20' into ORR

Trade-off between ORR Oil and Reservoir Oil

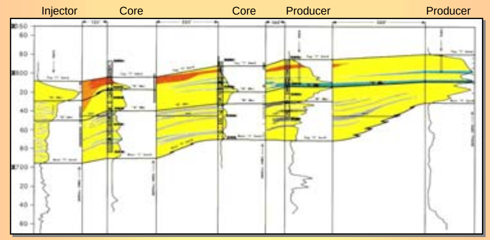


Comparison to Field *In Situ* Combustion

Oxygen Flood Pilot

- 200 Mscf O_2 injected, 3 year duration
- Gravity override observed
- Combustion temperature = 930-1020°F
- O_2/oil ratio = 4.1 kcf/bbl
- Porosity = 31%
- So = 30%
- Gravity = 21°API
- Perm (mD) = 200-6000

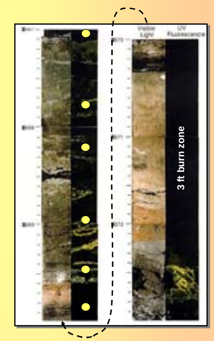
Legend
- Known burned
- Inferred burned
- Tight lime
- Sandstone
- Shale



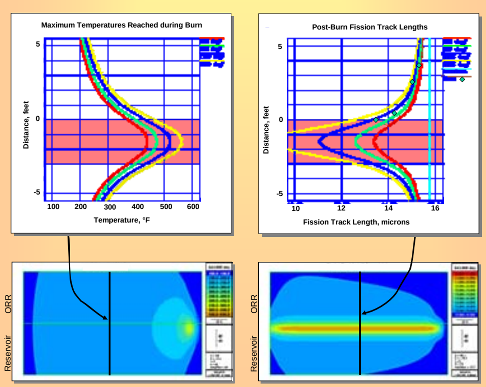
Apatite Fission Track Analysis

- Apatite fission track measurements made on post- burn core samples.
- Fission track annealing observed in samples near the 3-ft burn zone.
- Lengths of the longest (youngest) fission tracks are sensitive to the temperature history during combustion. These tracks are authigenic.

Fission Tracks in Apatite
$Ca_5(PO_4)_3(F,Cl,OH)$



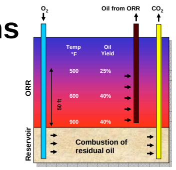
Analytic Model of Combustion Front Propagation



112 ft/year, 1100 °F adiabatic combustion temperature

Study Conclusions

ORRCA is technically feasible, but likely uneconomic.

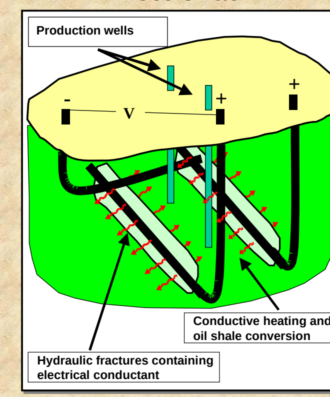


ORRCA Conclusions
- Appropriate ORR/reservoir pairs exist
- ORRCA can generate 175,000 bbl ORR oil in a 20-acre pattern
- ORRCA was not profitable given year-2000 economic climate

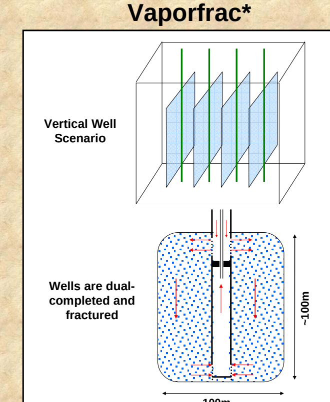
Future Actions
- Monitor oxygen separation technology for cost breakthroughs
- Monitor oil prices and revive ORRCA when profitable
- Pursue possible spin-off projects

Spinoff Ideas

Electrofrac*



Vaporfrac*



- Circulate heated naphtha in fractures.
- Coproduce naphtha and generated hydrocarbons.

* patents pending