SOURCE-RESERVOIRED OIL RESOURCES, ALASKAN NORTH SLOPE

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Alaska Department of Natural Resources, Division of Oil and Gas
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Talk Outline

- Unconventional Resources: terms and concepts
- North Slope Petroleum Systems
- Geologic Factors and Resource Evaluation Tools
- Drilling, Stimulation, and Production
- Analogues – Texas and North Dakota
- North Slope Sources: Distribution and Maturity
- North Alaska 2011 Areawide Lease Sales
- Summary
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Unconventional resources

Distinguished from conventional resources by

- **lower geologic risk**... hydrocarbons are almost certainly present everywhere within the play fairway

**BUT**

- **higher engineering risk**... not sure the resource will be recoverable everywhere (massive stimulations must succeed)
Unconventional terminology

Some are synonyms, others are not

- Resource plays
- Continuous accumulations
- Basin-centered accumulations
- Technology reservoirs
- Tight oil / gas
- Shale gas / shale oil ($\neq$ oil shale)
- Source-reservoired oil / gas
  
  ✓ Source = Reservoir = Trap
The Resource Pyramid

Conventional Reservoirs: Small Volumes, Easy to Develop

Unconventional Reservoirs: Large Volumes, Hard to Develop

- Tight Oil
- Heavy Oil
- Bituminous Sands

- Tight Gas Sands
- CBM
- Gas Shales

Huge Volumes, Difficult to Develop

- Gas Hydrates

Mining or in-situ retort

Province Resource Size

Increasing Product Price

Improving Technology

(modified from Sonnenberg, 2010)
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North Slope Region

Great Bear Petroleum 2010 lease purchase

Seismic transect
North Slope Petroleum Systems
3 prolific source rock intervals

Rock Column
- Nonmarine
- Marine Shelf
- Marine slope & basin
- Condensed marine shale

Legend
- Carbonates
- Metasedimentary
- Granite
- Hiatus or erosion

Modified by Alaska Division of Oil and Gas staff from Ken Bird and David Houseknecht (U.S. Geological Survey), personal communication, 2002.
Major North Slope Oil Source Rocks

- **Hue Shale/GRZ**
  - Cretaceous age, younger offshore to northeast
  - Shale deposited in sediment-starved & oxygen-depleted deep foreland basin
  - Separate tongues of different ages in west that coalesce eastward
  - Abundant volcanic ash beds altered to sticky clays (plastic behavior?)
  - Source of Tarn field oil (37 deg API)

- **lower Kingak Formation**
  - Early Jurassic age (just above Shublik Formation)
  - Shale deposited on sediment-starved & oxygen-depleted platform margin
  - Few well penetrations to south, rare outcrops in foothills
  - Lack details on regional distribution and source-reservoir characteristics
  - Source of Alpine field oil (40 deg API)

- **Shublik Formation**
  - Late Triassic age (just below Kingak Formation)
  - Phosphatic limestone, shale, sandstone, & siltstone deposited on nutrient-rich upwelling-influenced continental margin
  - Few well penetrations to south, common outcrops in foothills
  - Lack details on most source-reservoir characteristics
  - Source of Kuparuk field oil (24 deg API)
Central North Slope Seismic Transect

- GRZ-Hue Sh at ~8,000 – 13,000 ft depth
- Shublik + Lower Kingak at ~10,000 – 11,000 ft depth

(Decker, unpublished data, 2010-11)
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Key Geologic Factors -- Shale Resource Plays

- **Organic Geochemistry**
  - Total Organic Carbon content (richness)
  - Hydrogen Index (oil-prone, gas-prone, or inert kerogen types)
  - Oil properties (gravity, in-situ viscosity, wax & asphaltene content, etc.)

- **Thermal and Tectonic History**
  - Thermal maturity (immature → oil window → gas window → supermature)
  - Stress-strain history (# of phases of natural fracturing, etc.)
  - Current stress regime (determines orientation of artificial fractures and whether natural fractures are propped open)

- **Petrophysics**
  - Porosity (void space between grains, within grains, and in fractures)
  - Permeability (how connected are pore spaces?)
  - Relative Permeability (oil, gas, water – which flows more readily?)

- **Geomechanics** -- Is the rock brittle enough to create and sustain fractures?
  - Cement content and types (carbonate, silica, sulfides, etc.)
  - Grain content and types (silt, sand, fossil debris, etc.)
  - Layering (thickness and mechanical contrast)
Shale Resource Evaluation Tools

Core and Outcrop analyses
- RockEval – TOC (richness, kerogen type, general thermal maturity)
- Vitrinite Reflectance (thermal maturity)
- Porosity and Permeability
- Inorganic chemical content (XRD)
- Rock Mechanics testing
- Hydrocarbon desorption
- Optical and Scanning Electron Microscopy
- Fracture measurements and statistics

Wellbore and Well Log analyses
- Conventional logging suites
- Fracture imaging logs
- Magnetic Resonance, Photoelectric Effect, ...
- Delta Log-R log overlays
- Production testing → flow rates, pressure
- Microseismic monitoring of hydrofracture stimulations

Advanced seismic analyses
- AVO → Geomechanical brittleness (Incompressibility and Rigidity) for artificial fracs
- AVAZ → Anisotropy due to fractures or stress (zones prone to natural fractures)

Pore throats are less than 1 millionth of a meter across (15 microns (0.015 mm))
USGS currently assessing technically recoverable resources in source-rock systems of the North Slope

- Public geology review meeting in Anchorage on October 25, 2011
  - Present and solicit feedback on geological framework and assumptions
  - Methodology and L48 analogues

Basic resource assessment method:

- Determine cell size drained by a single well (e.g., 80 or 160 acres)
- Divide the play area into cells
- Determine probabilistic range of Estimated Ultimate Recovery (EUR) per well
  - production data
  - analogues
- Technically recoverable volume = EUR per cell x Number of cells
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Close Well Spacing, Many Pads

70 acres total surface impact (14 pads, 5 acres each) → 17,920 acres of subsurface development (2 mile-long laterals on each side of road times 7 miles length times 640 acres/mi²)

(Canadian Business Resources)

(courtesy Lynn Helms NDIC, DMR, 2011)
Close Well Spacing, Many Pads
Infrastructure-intensive development

- Bakken Shale  640 acres/well (Sanish & Parshall Fields)
- Eagle Ford Shale  125-140 acres/well (EOG plans)
- North Slope  ?  120-160 acres/well (Great Bear estimates)

*(Paneitz/ Whiting Petroleum, 2010)*
Frac FAQs

❖ How do they work?

*Fluid (water + sand + additives for gelling and gel-breaking, etc.) is pumped into an isolated part of the borehole under increasing pressure. When the fluid pressure exceeds the rock strength, the formation fractures and the sand-rich fluid shoots out into the growing cracks. The sand props the fractures open after the frac fluid flows back into the wellbore.*

❖ How much water do they use?

*Frac jobs for horizontal producers in L48 shale plays consume 1 to 5.5 million gallons of water (and millions of pounds of sand) per well, depending on rock properties, number of stages pumped, etc. (For comparison, ice roads require 1-1.5 million gallons per mile.)*

❖ What are the environmental risks?

*Contamination of fresh water aquifers with hydrocarbons and/or frac fluids is a potential concern where the hydrocarbon target and aquifer are not sufficiently separated. **THIS IS AVOIDABLE!**
Surface Water Limitations?

Kuparuk Uplands, White Hills, Franklin Bluffs, Foothills

(National Geographic, 2006; http://ngm.nationalgeographic.com/ngm/0605/feature1/map.html)
# Frac Fluids

Composition for a 16-stage West Virginia Marcellus Shale well

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Additive</th>
<th>Purpose</th>
<th>Use and Dilution</th>
<th>Actual Volume</th>
<th>Overall %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Carrier Fluid</td>
<td>Creates fracture network in shale and carry sand to the formation</td>
<td>Approximately 4 million gallons per well</td>
<td>7,416,622 gal</td>
<td>95.9926%</td>
</tr>
<tr>
<td>Sand</td>
<td>Sand</td>
<td>Enable fractures to remain open and allow gas to escape into the wellbore</td>
<td>Approximately 4 million pounds per well</td>
<td>296,255 gal</td>
<td>3.8343%</td>
</tr>
<tr>
<td>FR</td>
<td>Friction Reducer</td>
<td>Reduces friction between pipe and fluid</td>
<td>Diluted at one gallon per 1,000 gallons of water</td>
<td>6,318 gal</td>
<td>0.0818%</td>
</tr>
<tr>
<td>Biocide</td>
<td>Antimicrobial Agent</td>
<td>Eliminates bacteria in water sources</td>
<td>Diluted at one-half gallon per 1,000 gallons of water</td>
<td>1,069 gal</td>
<td>0.0141%</td>
</tr>
<tr>
<td>Scale Inhibitor</td>
<td>Scale Inhibitor</td>
<td>Prevents scale deposits</td>
<td>Diluted at one gallon per 1,000 gallons of water</td>
<td>1,057 gal</td>
<td>0.0137%</td>
</tr>
<tr>
<td>15% HCL</td>
<td>Acid</td>
<td>Dissolves cement and minerals in the perforations (non-diluted)</td>
<td>250 gallons per stage (non-diluted chemicals)</td>
<td>3,709 gal</td>
<td>0.0480%</td>
</tr>
<tr>
<td>Gelling Agent</td>
<td>Viscosifier</td>
<td>Adds viscosity to the fluid</td>
<td>Diluted at five gallons per 1,000 gallons of water</td>
<td>1,109 gal</td>
<td>0.0144%</td>
</tr>
<tr>
<td>Gel Breaker</td>
<td>Breaker</td>
<td>Reduces viscosity of fluid</td>
<td>Diluted at one-half gallons per 1,000 gallons of water</td>
<td>98 gal</td>
<td>0.0013%</td>
</tr>
</tbody>
</table>

![Fluid Frac Composition](http://www.eqt.com/docs/pdf/FluidCompositions/Well512456.pdf)

Source: EQT Energy, 2011
Frac Jobs
Where are the fractures and how far do they extend?

In this example, frac wings appear to extend ~450-550 ft to either side of the wellbore with some asymmetry.

34 frac trucks on location (Oil & Gas Journal)

Microseismic map of 9-stage hydraulically fractured horizontal well (Bello, 2009)
Frac Jobs
Where are the fractures and how far do they extend?

24-stage Bakken Formation frac

(Whiting Petroleum, 2011)
Single well flow rate over time

Shale gas well example

Rate drops off sharply early on

Lower rate continues for a long time at shallow decline rate

(Bello, 2009)
One producer’s average production profile for Bakken Formation production wells – North Dakota

- Successful shale wells produce at a relatively high initial rate
- Rates decline sharply early on, then decline more slowly
- Individual wells may produce for decades (depending on costs, etc.)

(Whiting Petroleum, 2011)
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Texas Analogue (?)
Upper Cretaceous Eagle Ford Shale (Boquillas Fm)
Texas Analogue (?)
Upper Cretaceous Eagle Ford Shale

(Treadgold and Nicklin, 2011)
Texas Analogue (?)
Upper Cretaceous Eagle Ford Shale

- Brittle: up to 70% calcite
- 50-250 ft thick; potentially all net pay
- 2-7% TOC
- Extensive area of thermal maturity
- Porosity 7-15%
- Narrow overpressure zone
North Dakota Analogue (?)
Devonian-Mississippian Bakken Fm – shale sandwich

(modified after Sonnenberg, 2011)
North Dakota Analogue (?)

Devonian-Mississippian Bakken Fm – First 60-90 day oil rates

• Brittle: siliceous & pyritic shales; dolomitic siltstone middle member
• Up to 100 ft thick “shale sandwich”
• Rich: 11% average TOC; up to 40%
• Oil-prone Type I/II kerogen
• Extensive area of thermal maturity
• Porosity 8-12%
• Permeability 0.05 – 0.5 mD
• Sweet spots relate to
  ✓ major flexures → natural fractures
  ✓ early oil window maturity → overpressure

(Nordeng, 2010; Nordeng and others, 2010)
Bakken Well Economics and Production
North Dakota Industrial Commission, Department of Mineral Resources

- Well Cost, Horizontal Producer: $6.1 million (47 jobs)
- Operating Cost, Monthly: <$7,000 (1 job)
- Royalty Rate: 16.7%
- Average Initial Production Rate: 955 BOPD
- Breakeven IP Oil Rate: 235 BOPD
- Breakeven Reserves per well: 183,000 bbl
- Breakeven Reserves Success: 83%

Marathon, Brigham, Whiting

(courtesy Lynn Helms NDIC, DMR, 2011)
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Shublilk Formation
Kavik River area outcrops

Interbedded shale, limestone, silty-muddy, phosphatic, pyritic (600 ft thick)
Shublik Formation
Well logs and zonation

lower Kingak Fm
Sag River Fm
Shublik Fm
Zone A
Zone B
Zone C
Zone D
Sadlerochit Gp

Rock Flour 1
Shublik Formation
Well logs and zonal correlations

(Decker, unpublished data, 2011)
Shublik-equivalent Otuk Fm

Oil-saturated lime mudstone fault breccia, Kukpowruk River
Shublik Fm Flow Tests
Kemik gas field: Naturally fractured reservoir (?)

**Gas Flow Rates**
- **Shublik A-B:** ~12 MMCFD (AOF?)
- **Shublik A-C:** ~10 MMCFD
- **Shublik C:** ~2 MMCFD
Shublik Fm Flow Tests
North Prudhoe Bay area – migrated oil (?)

W Kuparuk St 3-11-11

Gull Island St 1

1152 BOPD, 7/8” choke

2540 BOPD
Shublik Formation
Hydrogen Index and Thermal Maturity

(overlay figure from Peters and others, 2006)
Lower Kingak Formation

Log R source rock screening

Inigok 1

Itkillik River 1

Bush Fed 1

lower Kingak Fm source
~175-550 ft thick
Lower Kingak Formation
Hydrogen Index (???) and Thermal Maturity

(overlay figure from Peters and others, 2006)
Hue Shale/GRZ
Type section outcrops at Hue Creek, ANWR
Hue Shale/GRZ
Correlation Section and $\Delta$ Log R Total Organic Content estimates

<table>
<thead>
<tr>
<th>Location</th>
<th>Hue Sh</th>
<th>W Sak 26</th>
<th>Toolik 2</th>
<th>Hemi Spr 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Itkillik R 1</td>
<td>4.9%</td>
<td>2.6%</td>
<td>3.1%</td>
<td>4.8% (?)</td>
</tr>
<tr>
<td>Atlas 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narvaq 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W Sak 26</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toolik 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemi Spr 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\Delta$ Log R calculated TOC estimates

<table>
<thead>
<tr>
<th>Zone</th>
<th>Itkillik R 1</th>
<th>Atlas 1</th>
<th>Narvaq 1</th>
<th>W Sak 26</th>
<th>Toolik 2</th>
<th>Hemi Spr 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRZ</td>
<td>2.6%</td>
<td>2.4%</td>
<td>1.6%</td>
<td>5.0%</td>
<td>3.1%</td>
<td>10.3% (?)</td>
</tr>
<tr>
<td>Hue</td>
<td>4.9%</td>
<td>2.6%</td>
<td>3.1%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Decker, unpublished data, 2009)
Hue Shale/GRZ

Average Hydrogen Index and Thermal Maturity
# Source Rock Comparison

Geologic characteristics

<table>
<thead>
<tr>
<th></th>
<th>Bakken</th>
<th>Eagle Ford</th>
<th>Shublik</th>
<th>L. Kingak</th>
<th>Hue/GRZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Organic Carbon</td>
<td>10% avg</td>
<td>2-7%</td>
<td>2-3% avg</td>
<td>5% avg</td>
<td>3% avg</td>
</tr>
<tr>
<td>Main Kerogen Types</td>
<td>I/II (oil)</td>
<td>I/II (oil)</td>
<td>I/II-S (oil)</td>
<td>II/III (oil-gas)</td>
<td>II/III (oil-gas)</td>
</tr>
<tr>
<td>Oil Gravity, °API</td>
<td>42°</td>
<td>30-50°</td>
<td>24-45°</td>
<td>40°</td>
<td>38°</td>
</tr>
<tr>
<td>Thickness</td>
<td>up to 100 ft</td>
<td>50-250 ft</td>
<td>0-600 ft</td>
<td>175-550 ft</td>
<td>100-800 ft</td>
</tr>
<tr>
<td>Thermal Maturity</td>
<td>Imm-Oil-Gas</td>
<td>Imm-Oil-Gas</td>
<td>Imm-Oil-Gas</td>
<td>Imm-Oil-Gas</td>
<td>Imm-Oil-Gas</td>
</tr>
<tr>
<td>Lithology &amp; Variability</td>
<td>Sh-Slts-Sh</td>
<td>Sh-Slts-Ls</td>
<td>Sh-Slts-Ls</td>
<td>Shale</td>
<td>Sh-Tuff</td>
</tr>
<tr>
<td>Brittleness</td>
<td>Yes - Quartz</td>
<td>Yes - Calcite</td>
<td>Yes - Calcite</td>
<td>No ?</td>
<td>No ?</td>
</tr>
<tr>
<td>Natural Fractures</td>
<td>Yes</td>
<td>Locally</td>
<td>some zones</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Overpressure</td>
<td>Yes</td>
<td>Locally</td>
<td>?</td>
<td>Probably</td>
<td>Locally</td>
</tr>
</tbody>
</table>

(compiled from various sources, Decker, 2011)
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North Alaska 2011 Areawide Lease Sales

Rescheduled to December 7 -- All available unleased State tracts

North Slope Areawide Sale

Beaufort Sea Areawide Sale

North Slope Foothills Areawide Sale
2011 North Alaska Areawide Lease Sales

Three competitive oil and gas lease sales encompassing 14.7 million acres, re-scheduled to December 7, 2011.

- **North Slope Areawide**
  - Encompasses 5.1 million acres onshore, including the core producing area north of the Umiat baseline between NPRA and ANWR
  - Barrow Arch crest and southern flank, northern Colville Basin
  - Conventional oil and gas prospects in structural, stratigraphic, and combination traps
  - Shale oil fairway as currently understood

- **Beaufort Sea Areawide**
  - Encompasses 2 million acres in state waters and coastal areas
  - Barrow Arch and faulted northern margin
  - Oil and gas prospects in extensional, stratigraphic, and combination traps

- **North Slope Foothills Areawide**
  - Encompasses 7.6 million acres south of the Umiat baseline between NPRA and ANWR
  - Colville Basin and Brooks Range foothills
  - Mainly gas prospects in compressional anticlines
North Slope Areawide Lease Sale
Now scheduled for December 7, 2011
Many variables impact productivity of source-reserviced oil and gas

- Organic geochemistry
- Thermal and tectonic history
- Petrophysics
- Geomechanics
- Drilling and completion practices

Development of North Slope shale oil will likely depend on

- Successful exploration drilling, data gathering to establish geological favorability
- Successful production pilot project(s)
- Lowering drilling and operating costs
- All-season roads for year-round surface access to new areas
- More hydraulic frac crews
- Sufficient water supplies for frac make-up fluid
- Factual understanding and operator transparency regarding frac practices
References Cited


