Source-Reservoired Oil Resources
Alaskan North Slope

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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

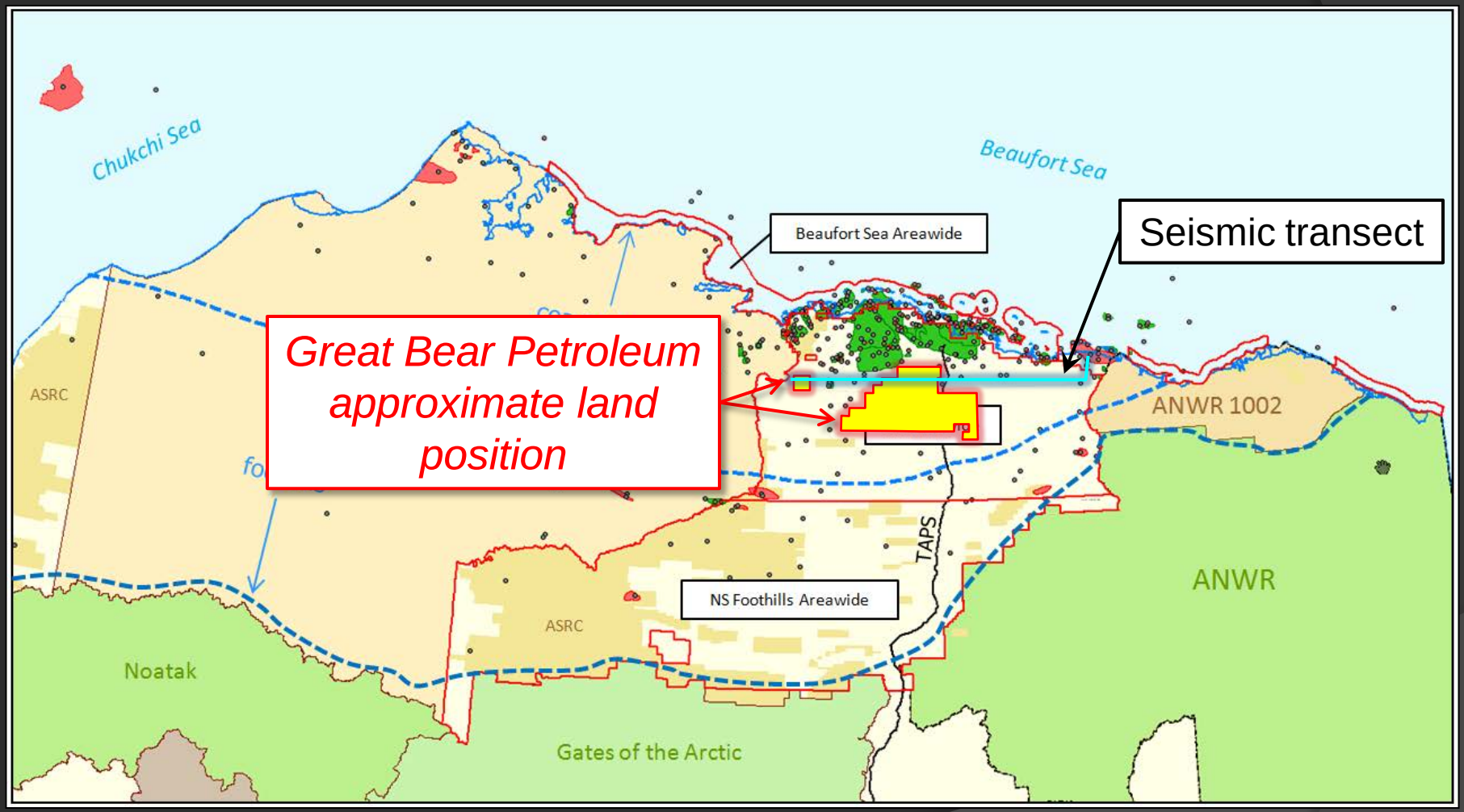
- **higher engineering risk…** not sure the resource will be recoverable everywhere (massive stimulations must succeed)

Unconventional terminology

Some terms are more specific than others

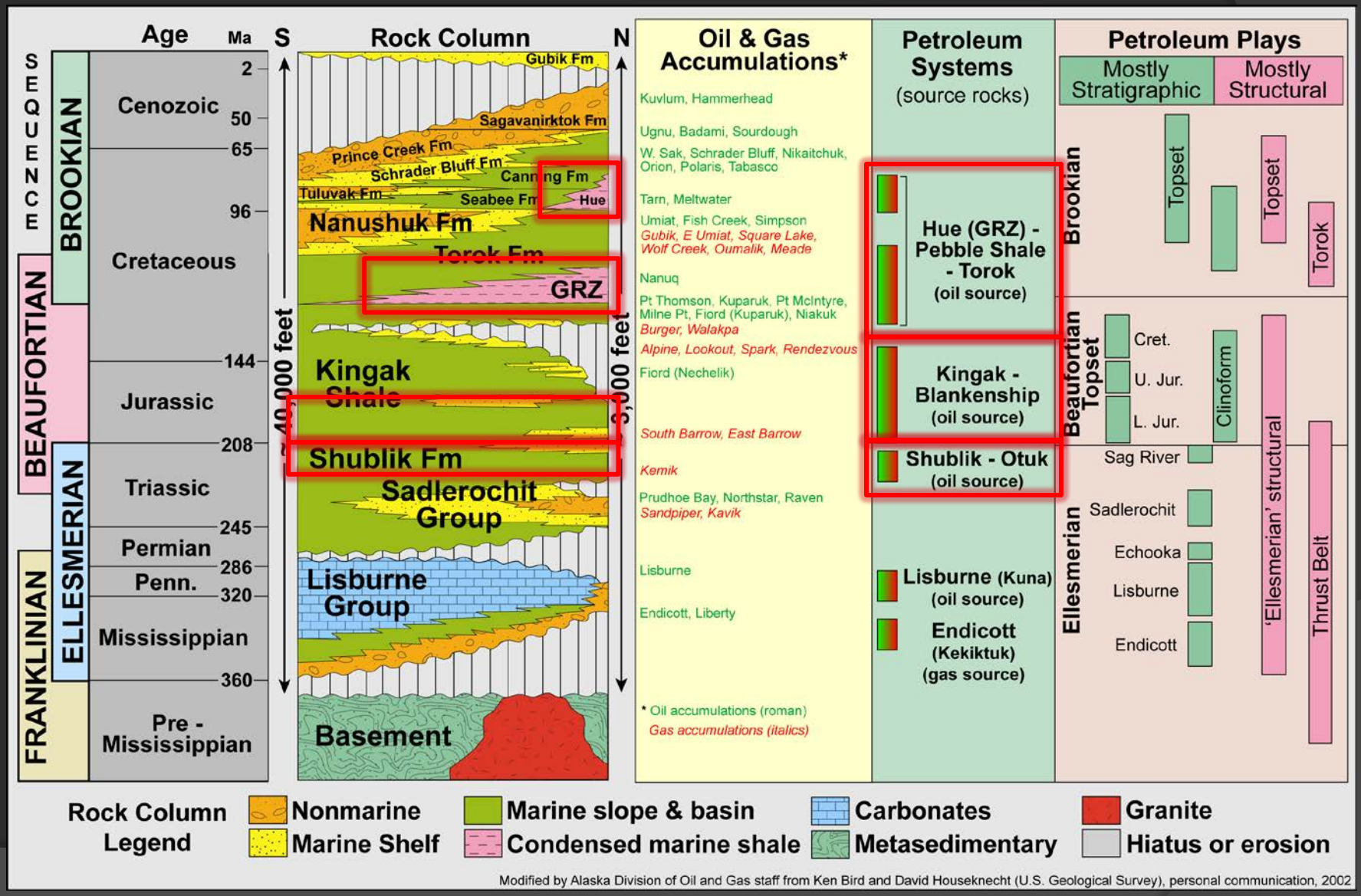
- Resource plays
- Continuous accumulations
- Basin-centered accumulations
- Technology reservoirs
- Tight oil / gas
- Shale gas / shale oil (≠ oil shale)
- Source-reservoired oil / gas
  - ✓ *Source = Reservoir = Trap*

North Slope Region



North Slope Petroleum Systems

3 prolific source rock intervals

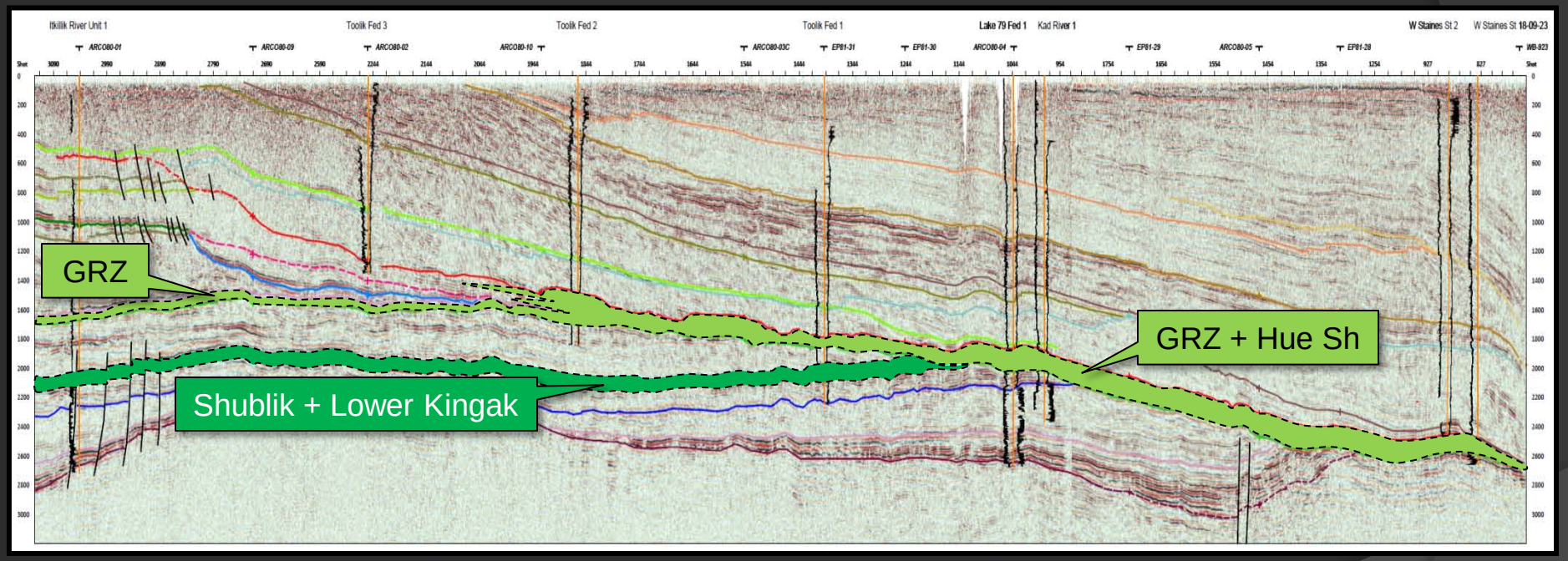


Modified by Alaska Division of Oil and Gas staff from Ken Bird and David Houseknecht (U.S. Geological Survey), personal communication, 2002

Central North Slope Seismic Transect

Public Seismic Line ARCO 80-07& 80-06

West *Total length ~120 miles* East



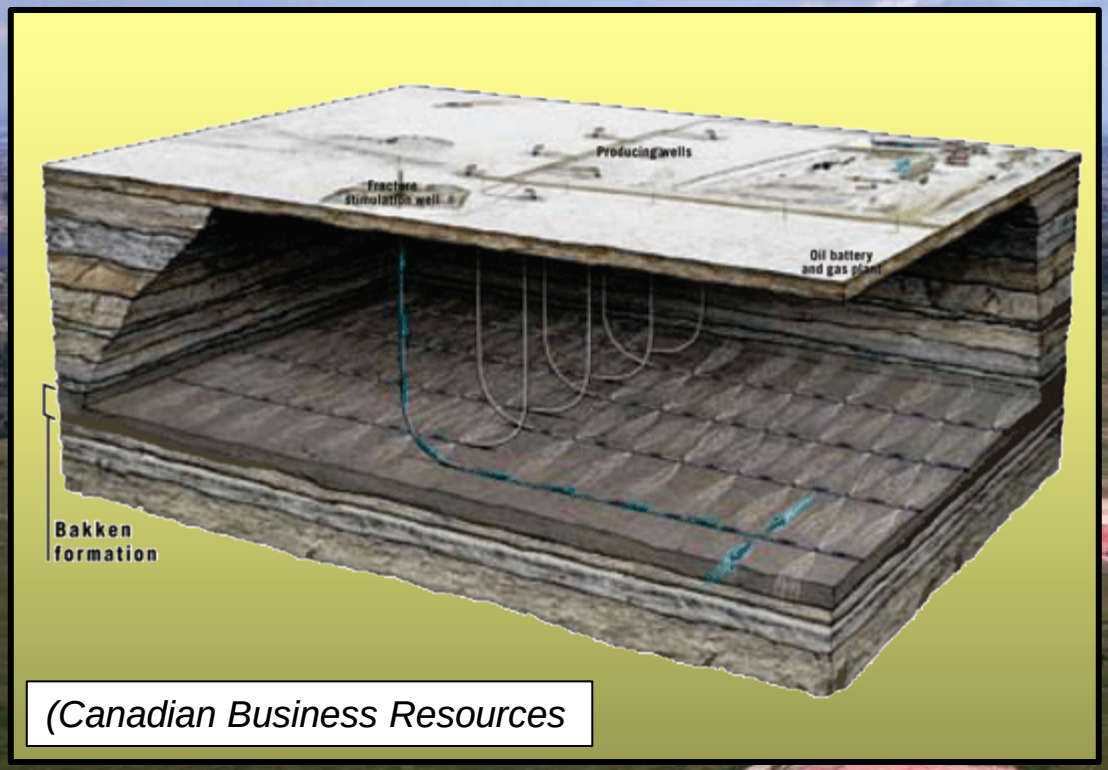
- GRZ-Hue Sh at ~8,000 – 13,000 ft depth
- Shublik + Lower Kingak at ~10,000 ft depth

(Decker, unpublished data, 2010-11)

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)

Close Well Spacing, Many Pads



(Canadian Business Resources

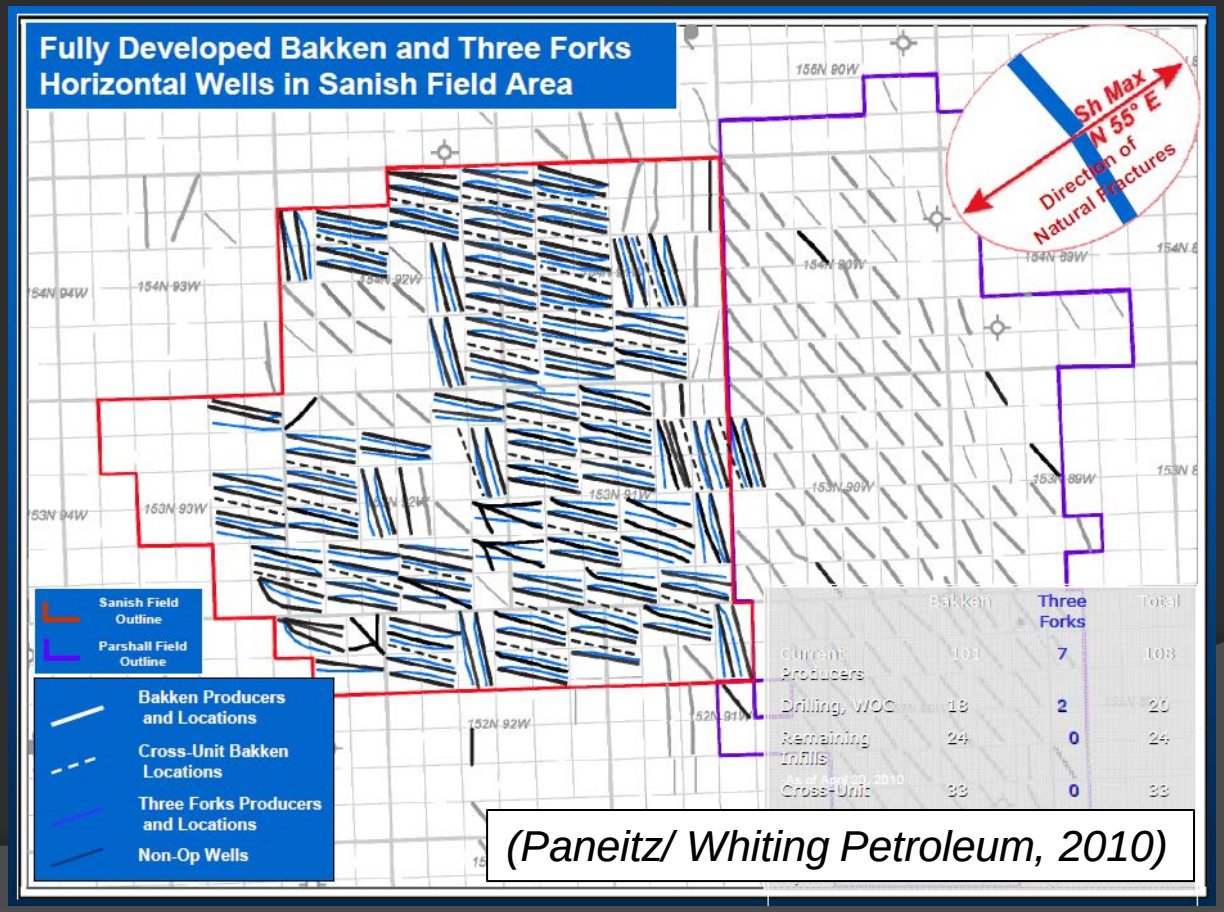
70 acres total surface impact (14 pads, 5 acres each) → 17,920 acres of subsurface development (2 mile-long laterals on each side of road times 7 miles length times 640 acres/mi^2)

(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?

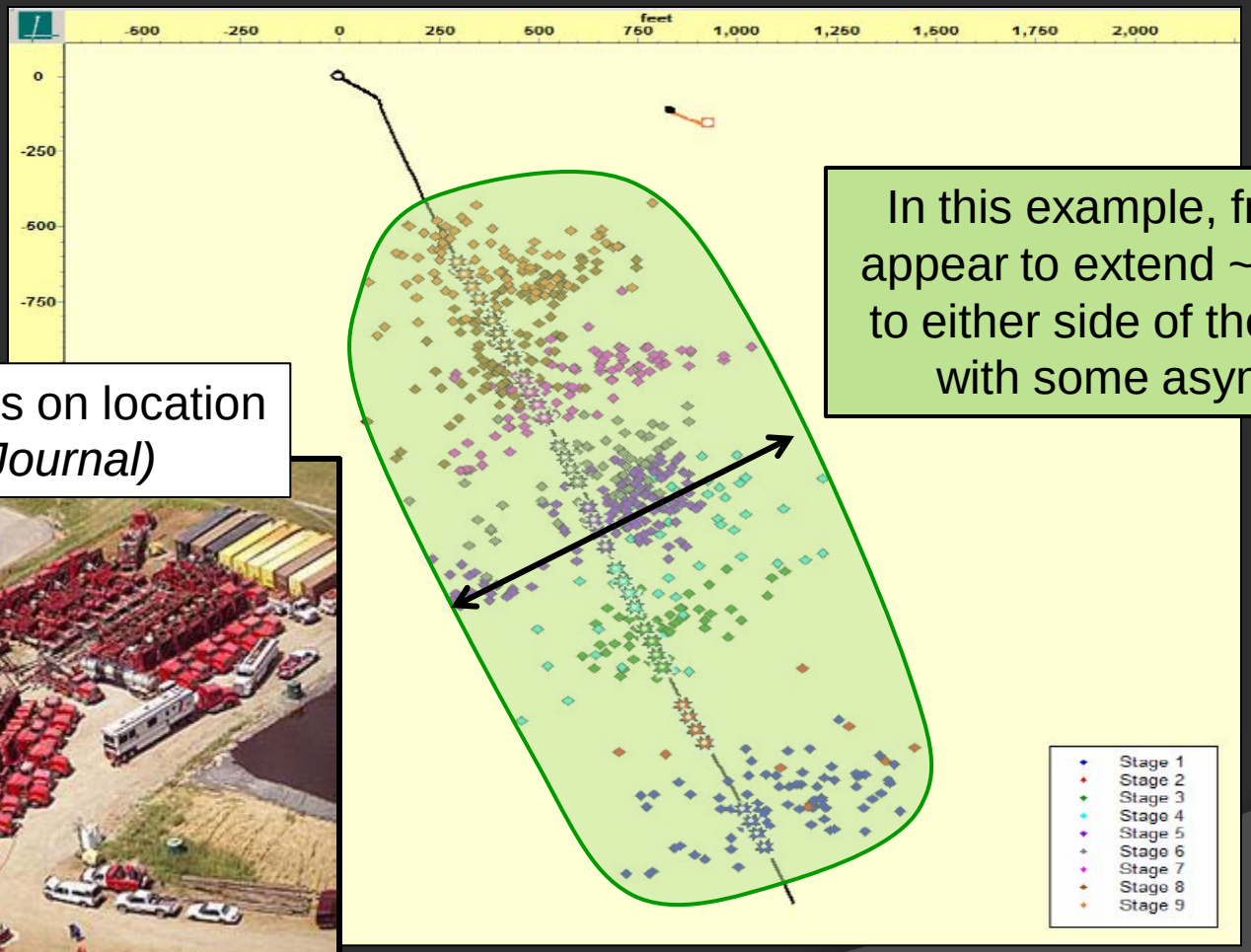
  Frac jobs for horizontal producers in L48 shale plays consume 1 to 5.5 million gallons of water (and millions of pounds of sand) per well, depending on rock properties, number of stages pumped, etc.

- What are the environmental risks?

  Contamination of fresh water aquifers with hydrocarbons and/or frac fluids can occur where the hydrocarbon target and aquifer are not sufficiently separated. ***THIS SHOULD BE AVOIDABLE!***

Frac Jobs

Where are the fractures and how far do they extend?



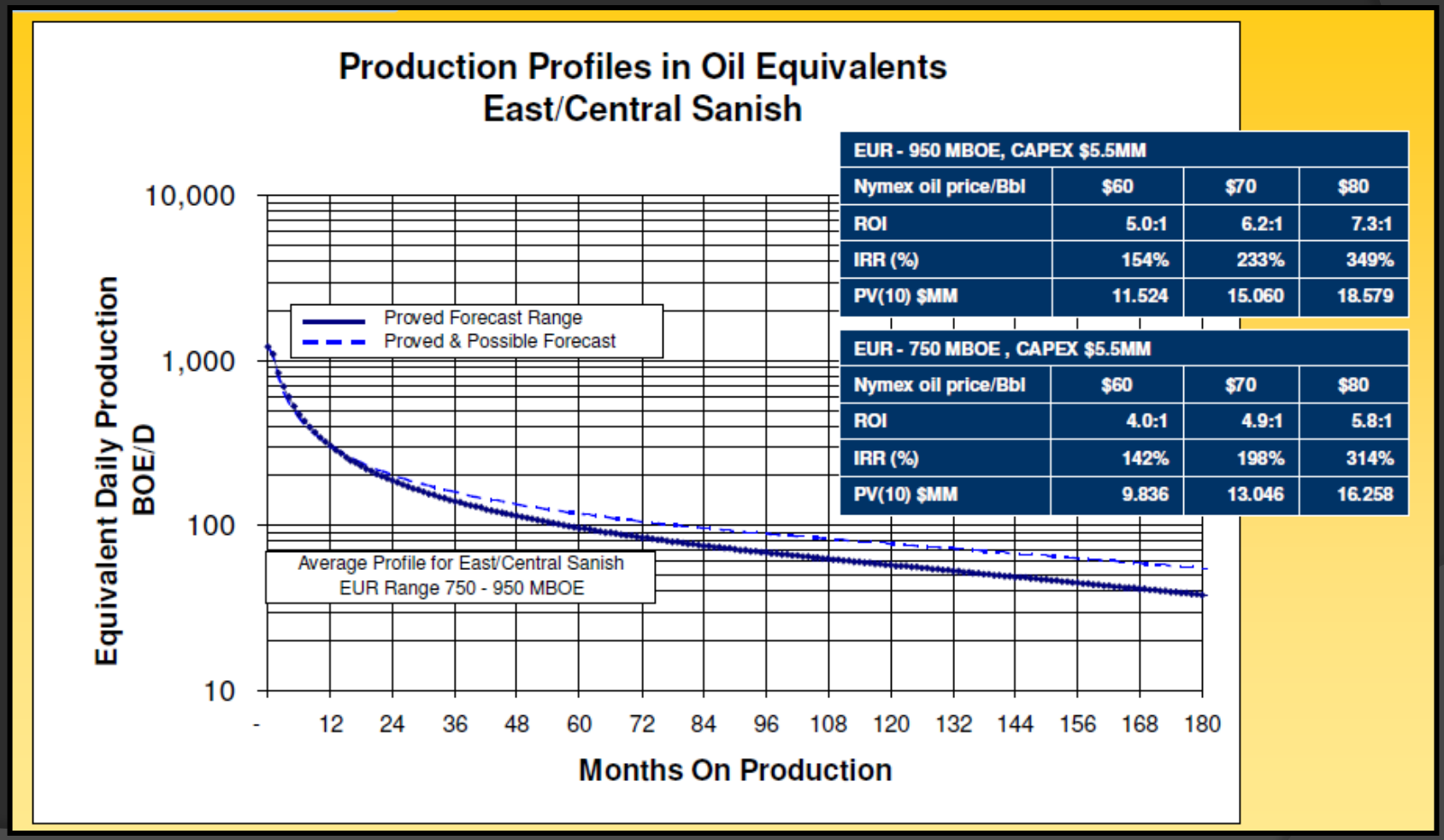
In this example, frac wings appear to extend ~450-550 ft to either side of the wellbore with some asymmetry

34 frac trucks on location *(Oil & Gas Journal)*

Microseismic map of 9-stage hydraulically fractured horizontal well *(Bello, 2009)*

Single well flow rate over time

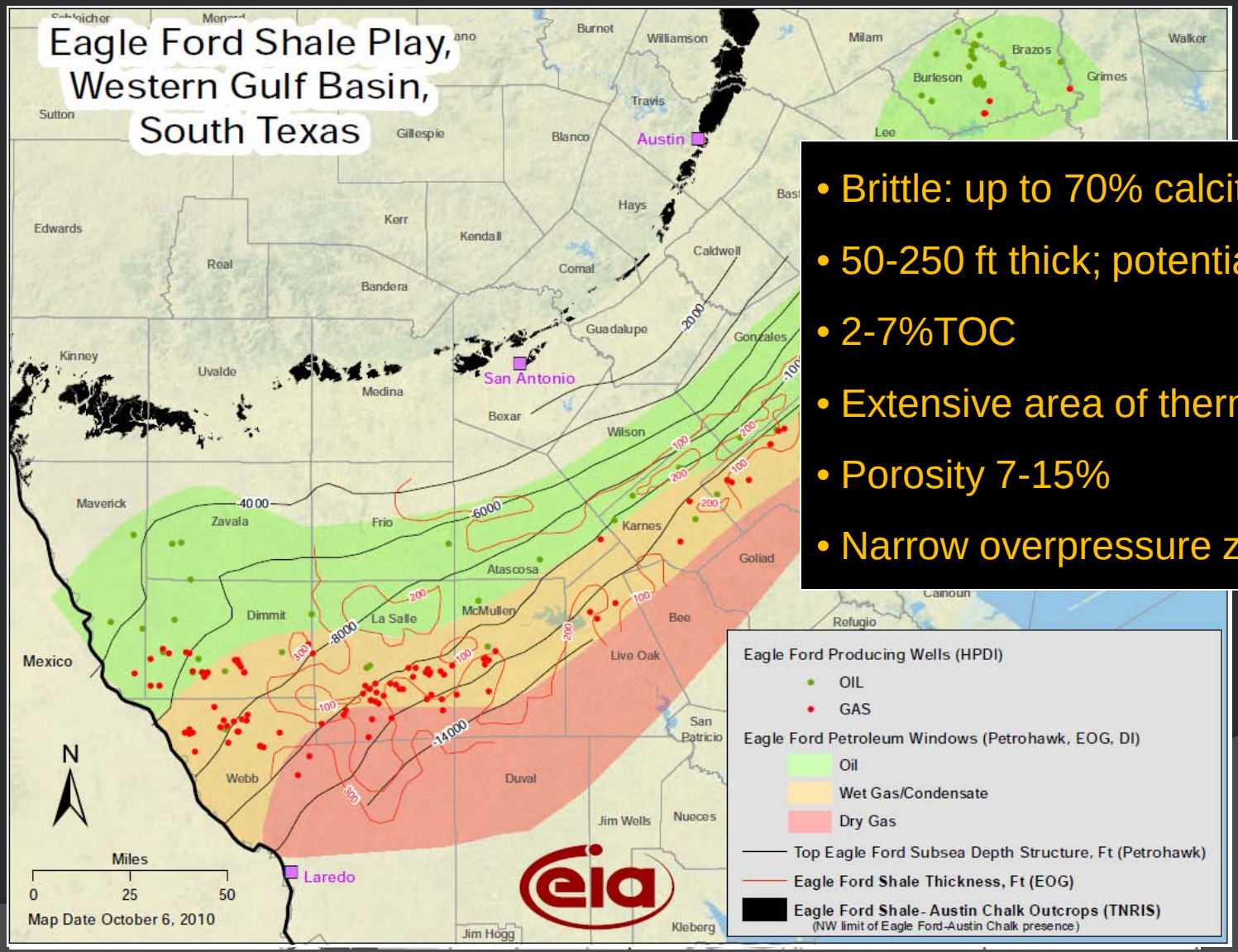
One producer's average production profile for Bakken Formation production wells – North Dakota



(Whiting Petroleum, 2011)

Texas Analogue (?)

Upper Cretaceous Eagle Ford Shale

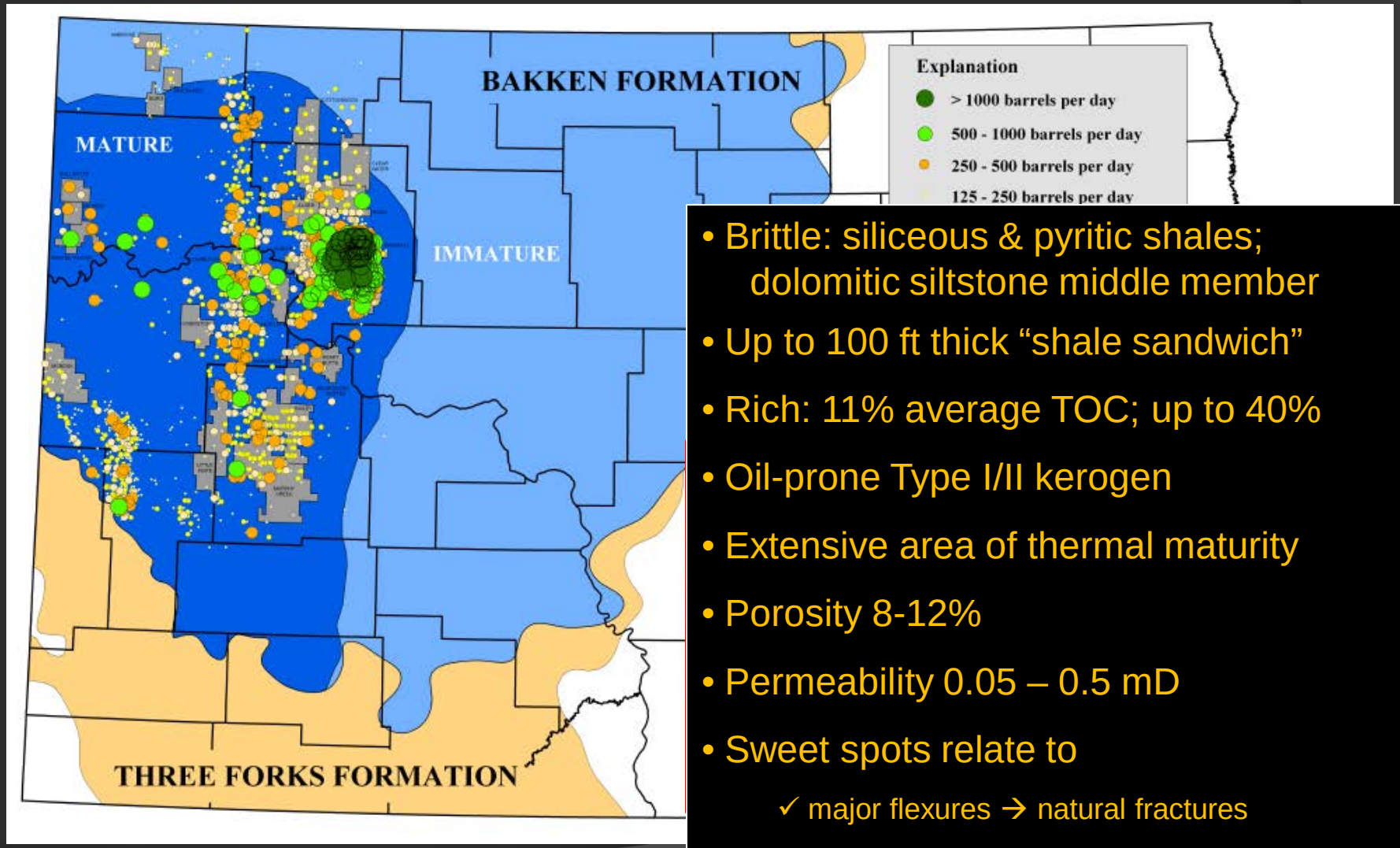


- Brittle: up to 70% calcite
- 50-250 ft thick; potentially all net pay
- 2-7%TOC
- Extensive area of thermal maturity
- Porosity 7-15%
- Narrow overpressure zone

(Energy Information Administration, 2010)

North Dakota Analogue (?)

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



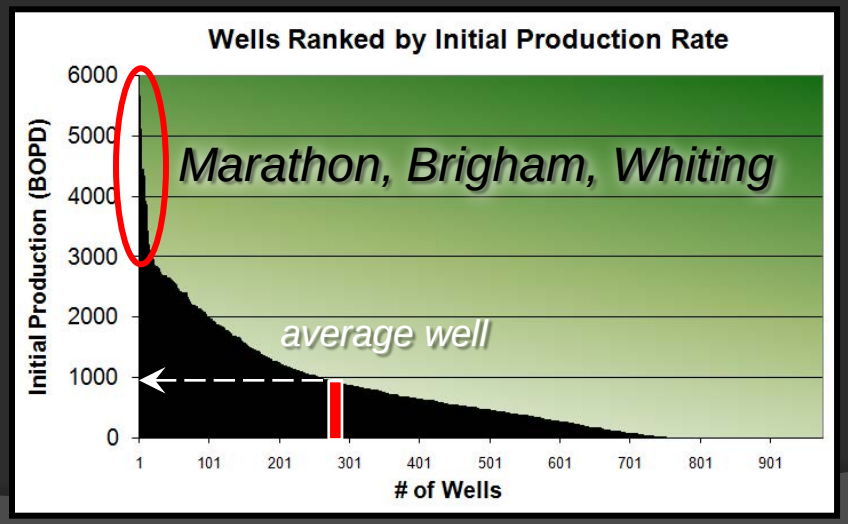
- Brittle: siliceous & pyritic shales; dolomitic siltstone middle member
- Up to 100 ft thick "shale sandwich"
- Rich: 11% average TOC; up to 40%
- Oil-prone Type I/II kerogen
- Extensive area of thermal maturity
- Porosity 8-12%
- Permeability 0.05 – 0.5 mD
- Sweet spots relate to
  - ✓ major flexures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

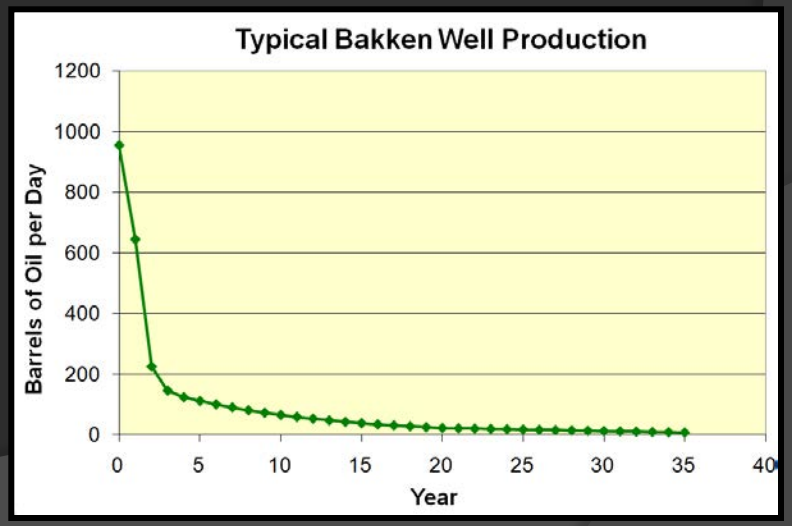
(Nordeng, 2010; Nordeng and others, 2010)

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%





(courtesy Lynn Helms NDIC, DMR, 2011)

Shublik Formation

Variability in outcrop and well logs

Interbedded shale & limestone, silty-muddy, phosphatic, pyritic (up to 600 ft thick)

Shublik Fm

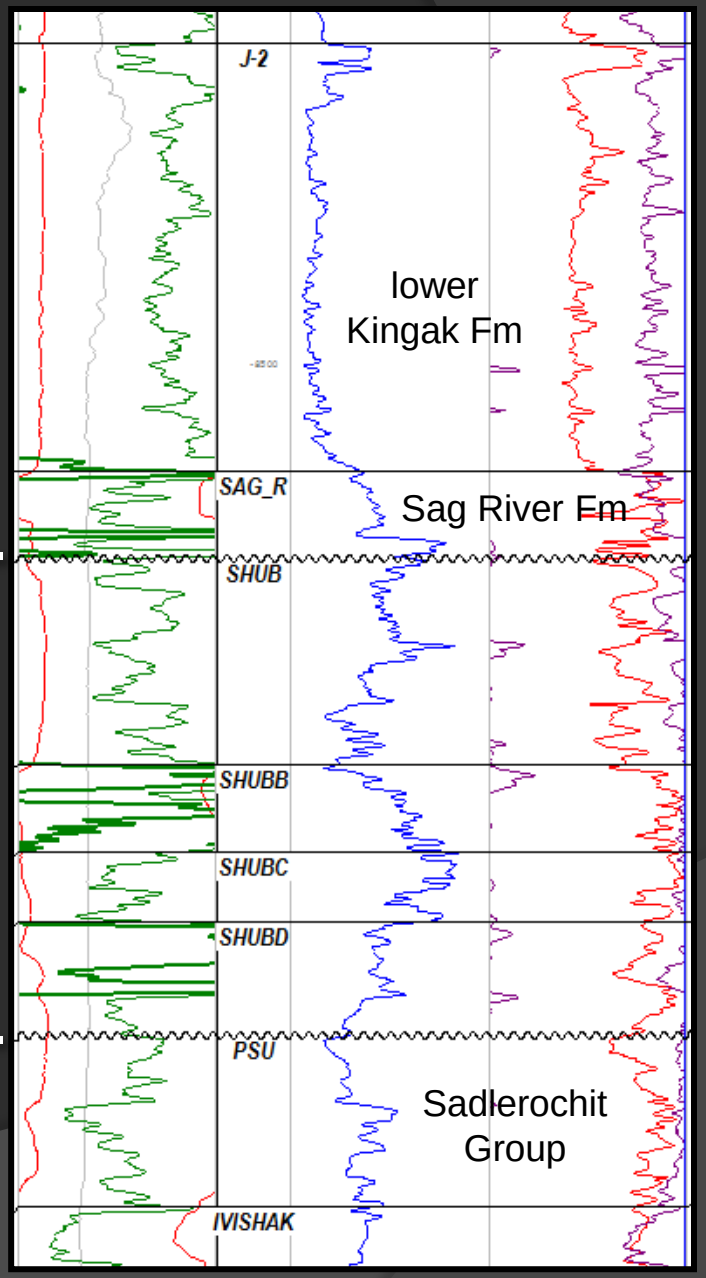
Zone A

Zone B

Zone C

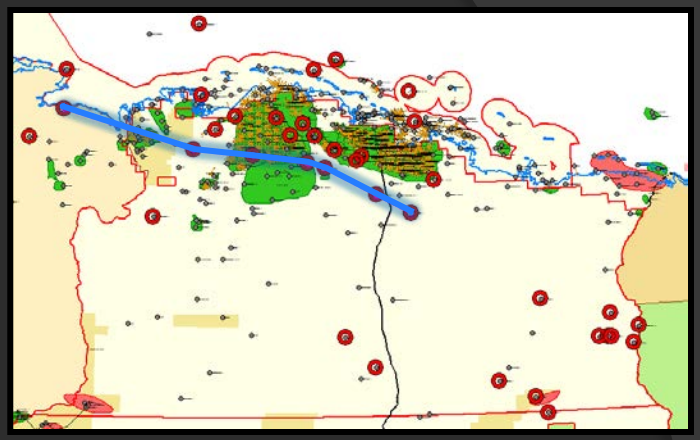
Zone D

Rock Flour 1

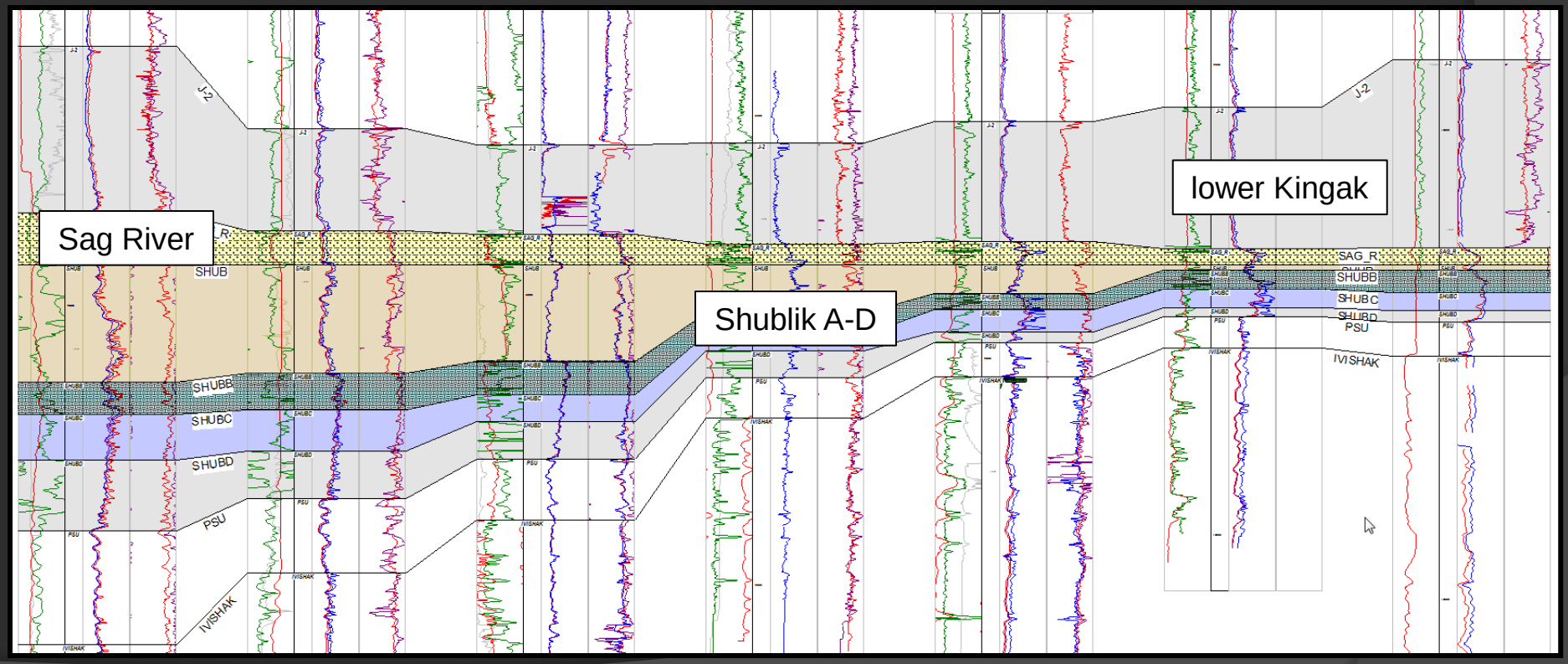


Shublik Formation

Well logs and zonal correlations



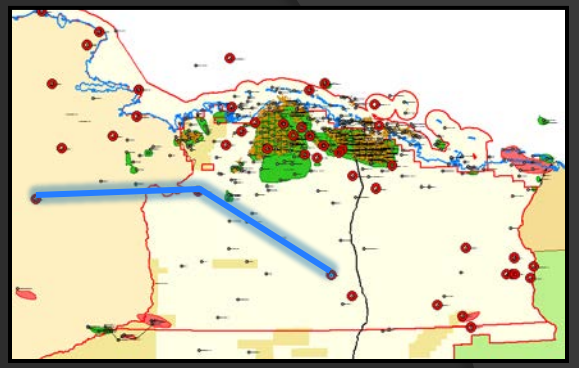
S Harr Bay 1 *Kookpuk 1* *KRU 2F-20* *Rock Flour 1* *Hemi Spr 1* *Hemi Spr 3* *Toolik 1*



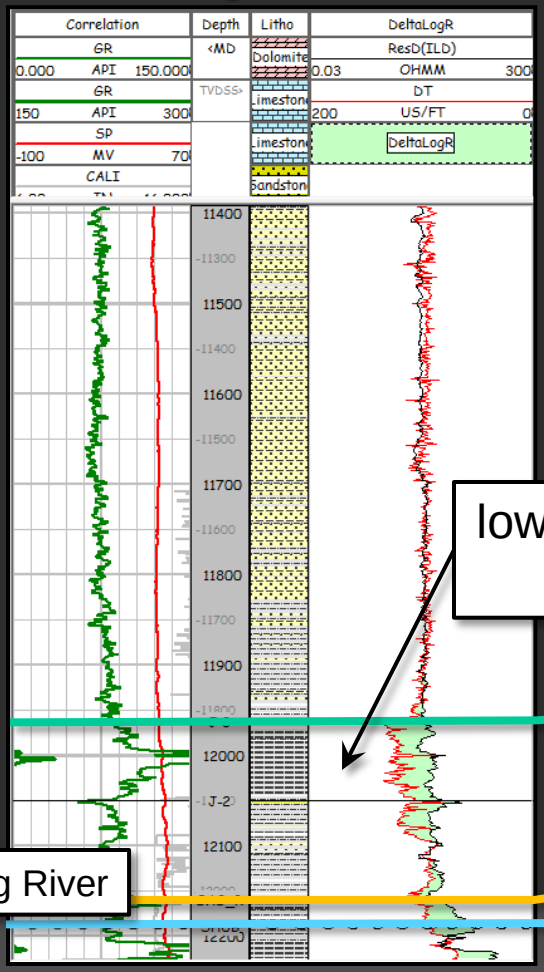
(Decker, unpublished data, 2011)

Lower Kingak Formation

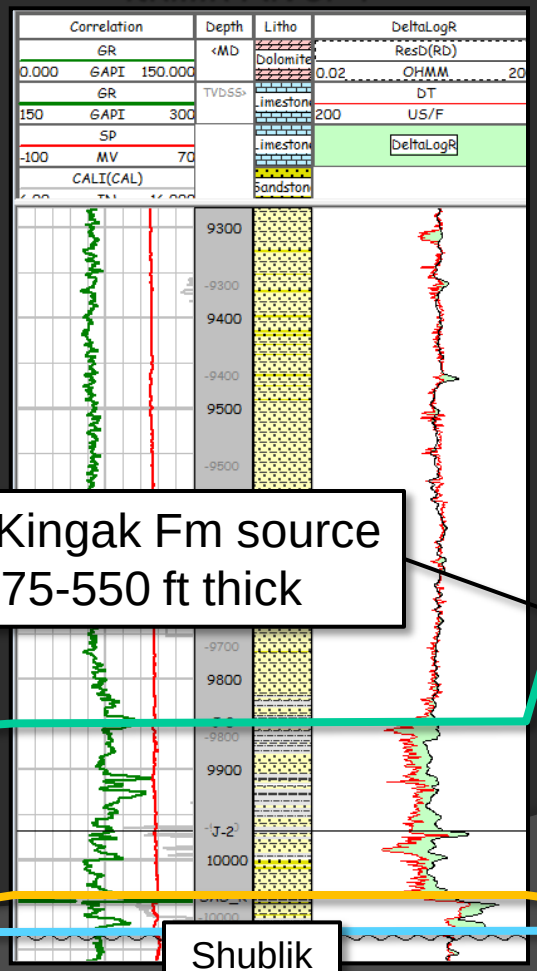
∆ Log R source rock screening



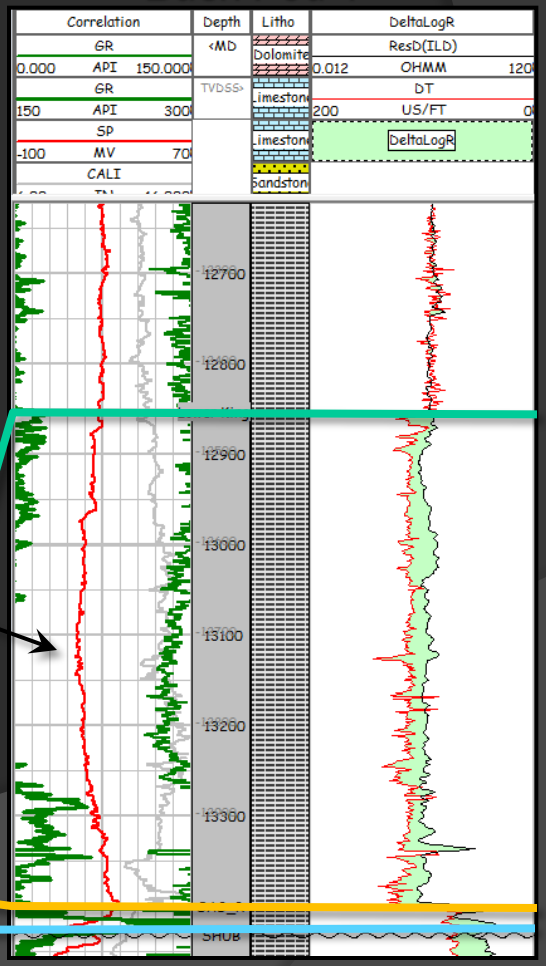
Inigok 1



Itkillik River 1



Bush Fed 1



lower Kingak Fm source
~175-550 ft thick

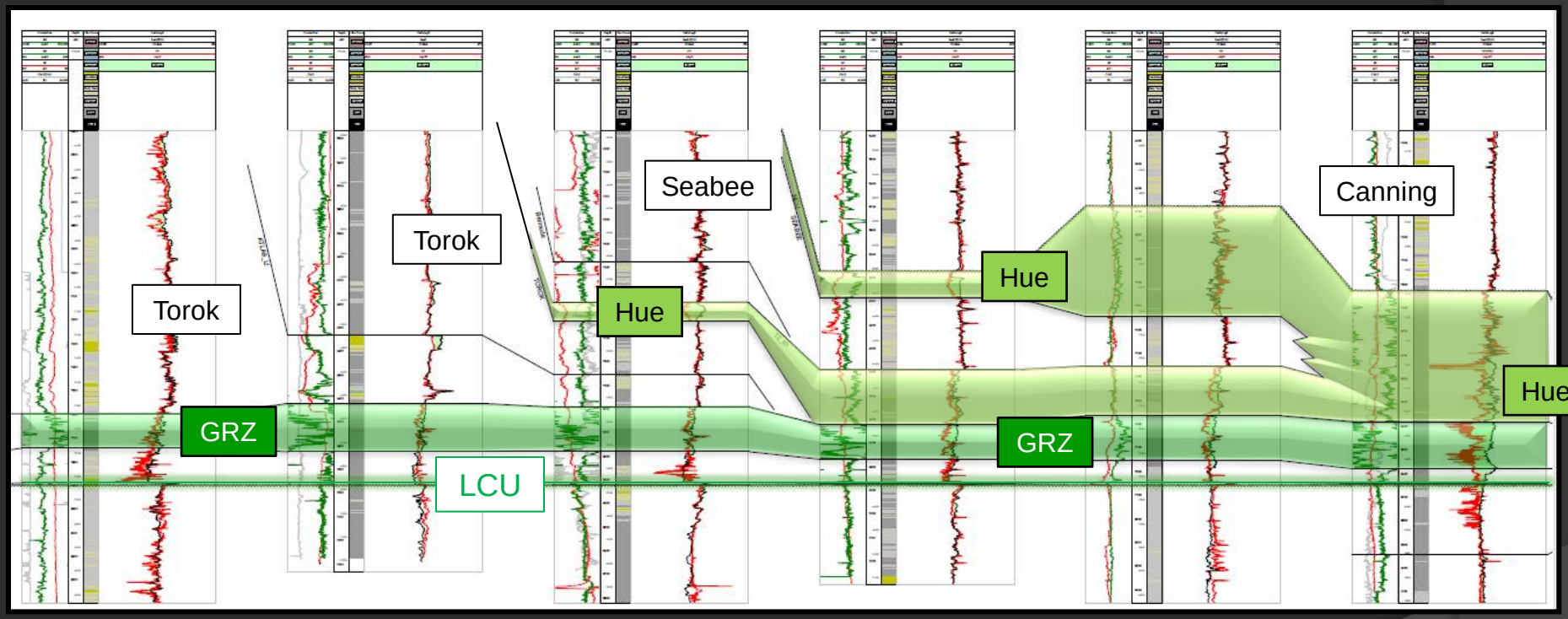
Sag River

Shublik

Hue Shale/GRZ

Correlations and log-based Total Organic Content estimates

Itkillik R 1 *Atlas 1* *Narvaq 1* *W Sak 26* *Toolik 2* *Hemi Spr 3*

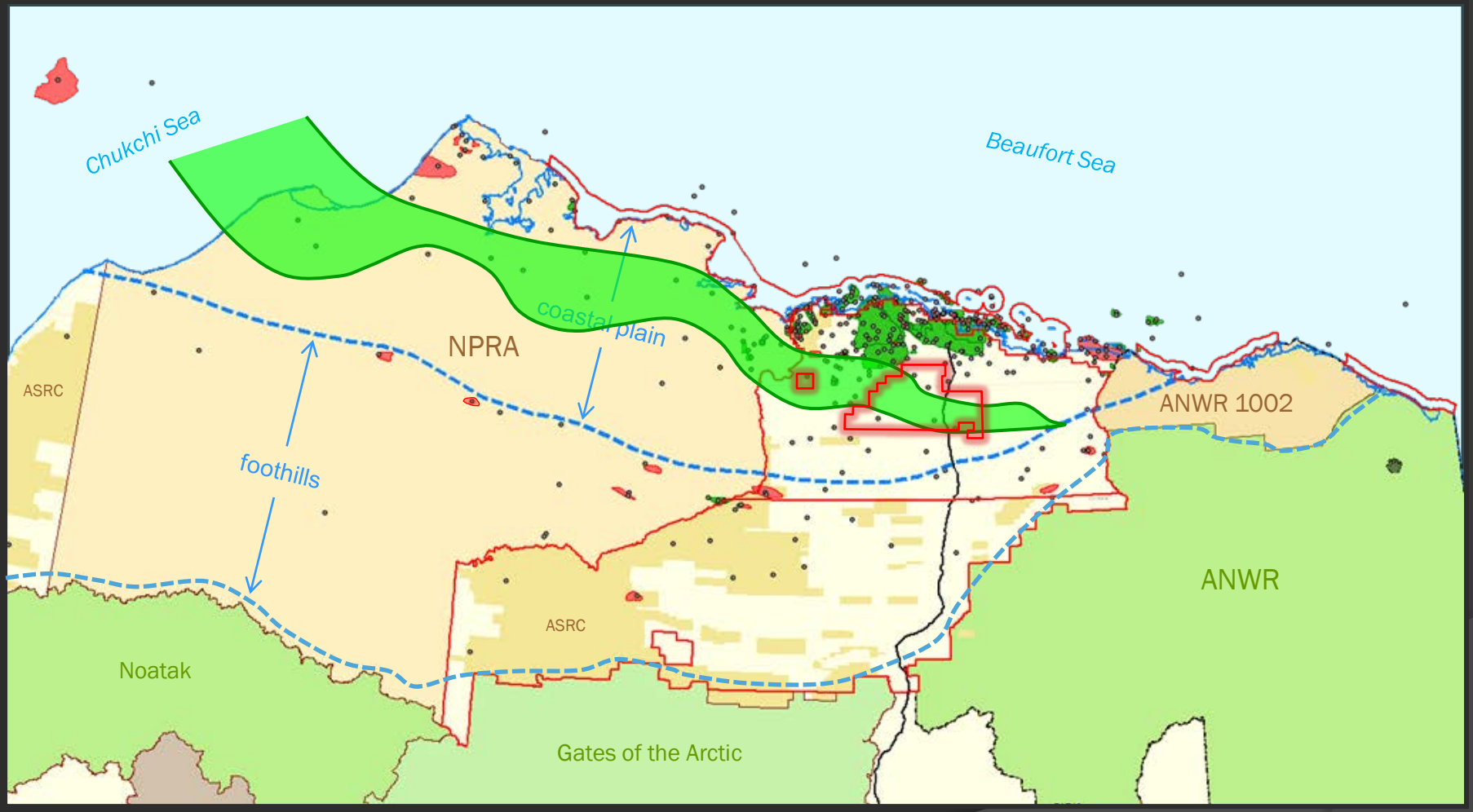


Δ Log R calculated TOC estimates					
Hue Sh	4.9%	2.6%	3.1%	4.8% (?)	
GRZ	2.6%	2.4%	1.6%	5.0%	3.1%	10.3% (?)

(Decker, unpublished data, 2009)

Shublik and Lower Kingak Formations

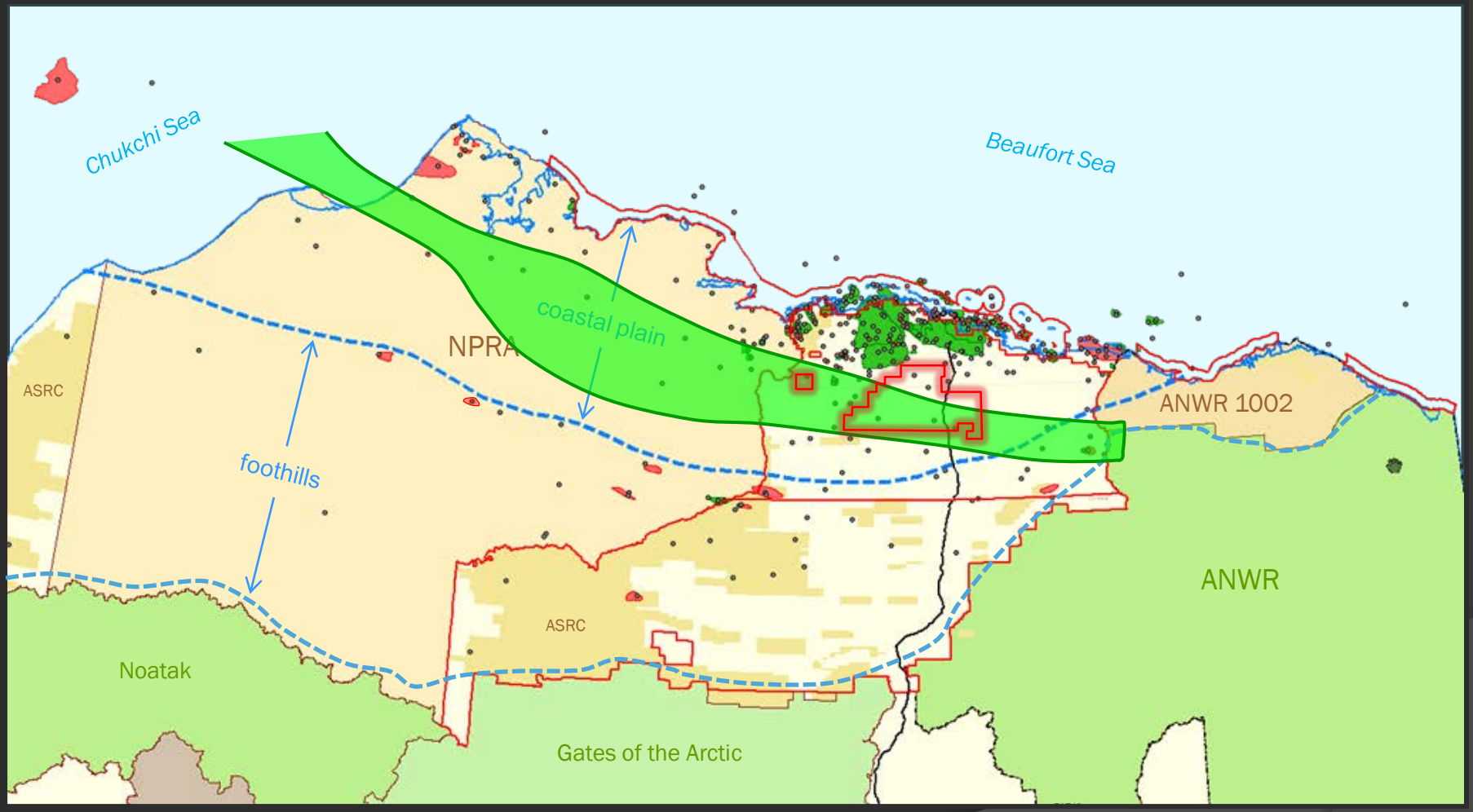
Thermal Maturity Zone



(mature area after Peters and others, 2006)

Hue Shale/GRZ

Thermal Maturity Zone



(mature area after Peters and others, 2006)

Comparison

Source rock characteristics

	Bakken	Eagle Ford	Shublik	L. Kingak	Hue/GRZ
Total Organic Carbon	10% avg	2-7%	2.4% avg	5% avg	3% avg
Main Kerogen Types	I/II (oil)	I/II (oil)	I/II-S (oil)	II/III (oil-gas)	II/III (oil-gas)
Oil Gravity, °API	42°	30-50°	24°	40°	38°
Thickness	up to 100 ft	50-250 ft	0-600 ft	175-550 ft	100-800 ft
Thermal Maturity	Imm-Oil-Gas	Imm-Oil-Gas	Imm-Oil-Gas	Imm-Oil-Gas	Imm-Oil-Gas
Lithology & Variability	Sh-Slts-Sh	Sh-Slts-Ls	Sh-Slts-Ls	Shale	Sh-Tuff
Brittleness	Yes - Quartz	Yes - Calcite	Yes - Calcite	No ?	No ?
Natural Fractures	Yes	Locally	some zones	?	?
Overpressure	Yes	Locally	?	Probably	Locally

(compiled from various sources, Decker, 2011)

Summary

- Many variables impact productivity of source-reservoired 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