SOURCE-RESERVOIRED OIL RESOURCES,

ALASKAN NORTH SLOPE

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Alaska Department of Natural Resources, Division of Oil and Gas
September 15, 2011

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

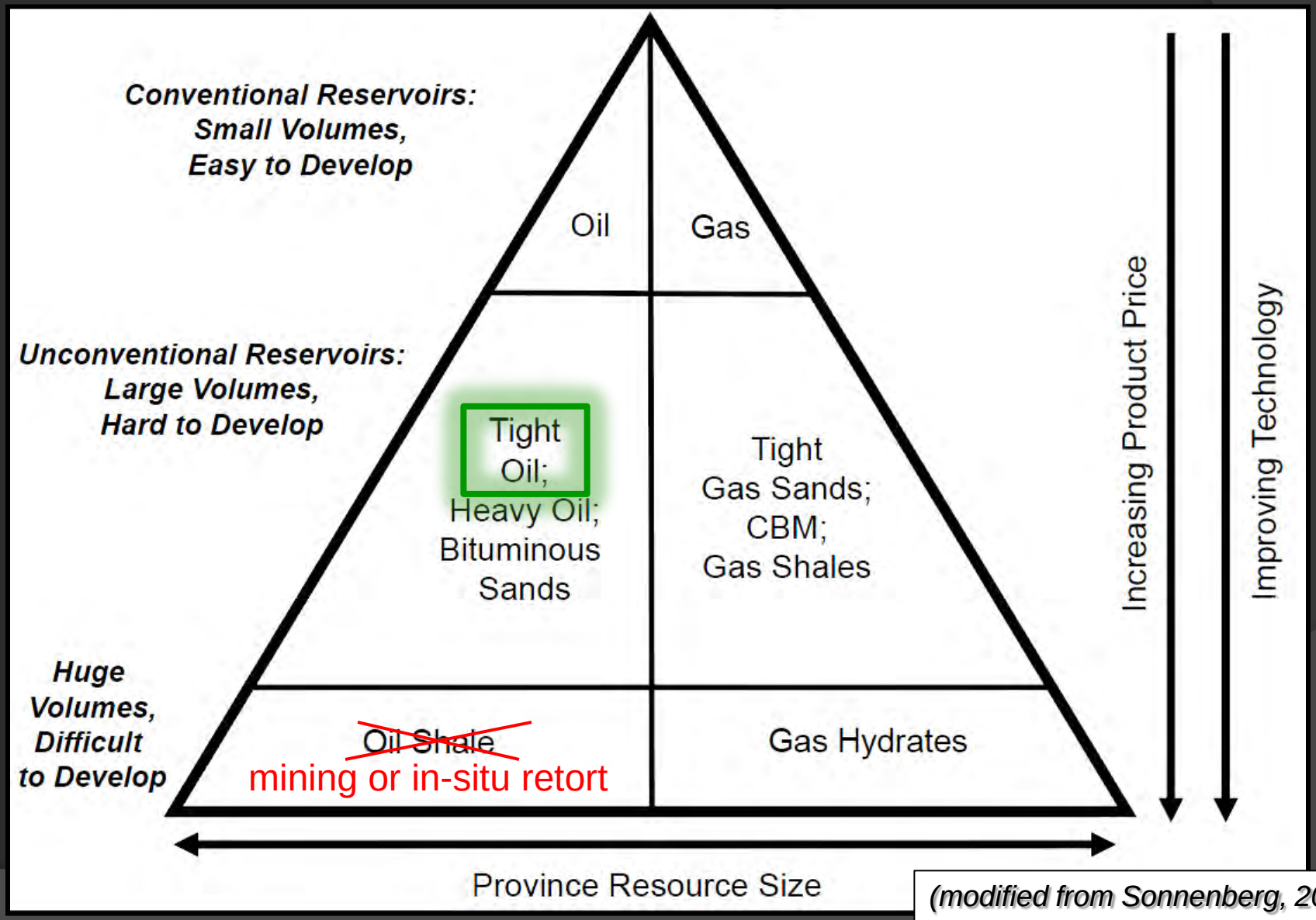
- **higher engineering risk…** not sure the resource will be recoverable everywhere (massive stimulations must succeed)

Unconventional terminology

Some are synonyms, others are not

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

The Resource Pyramid



(modified from Sonnenberg, 2010)

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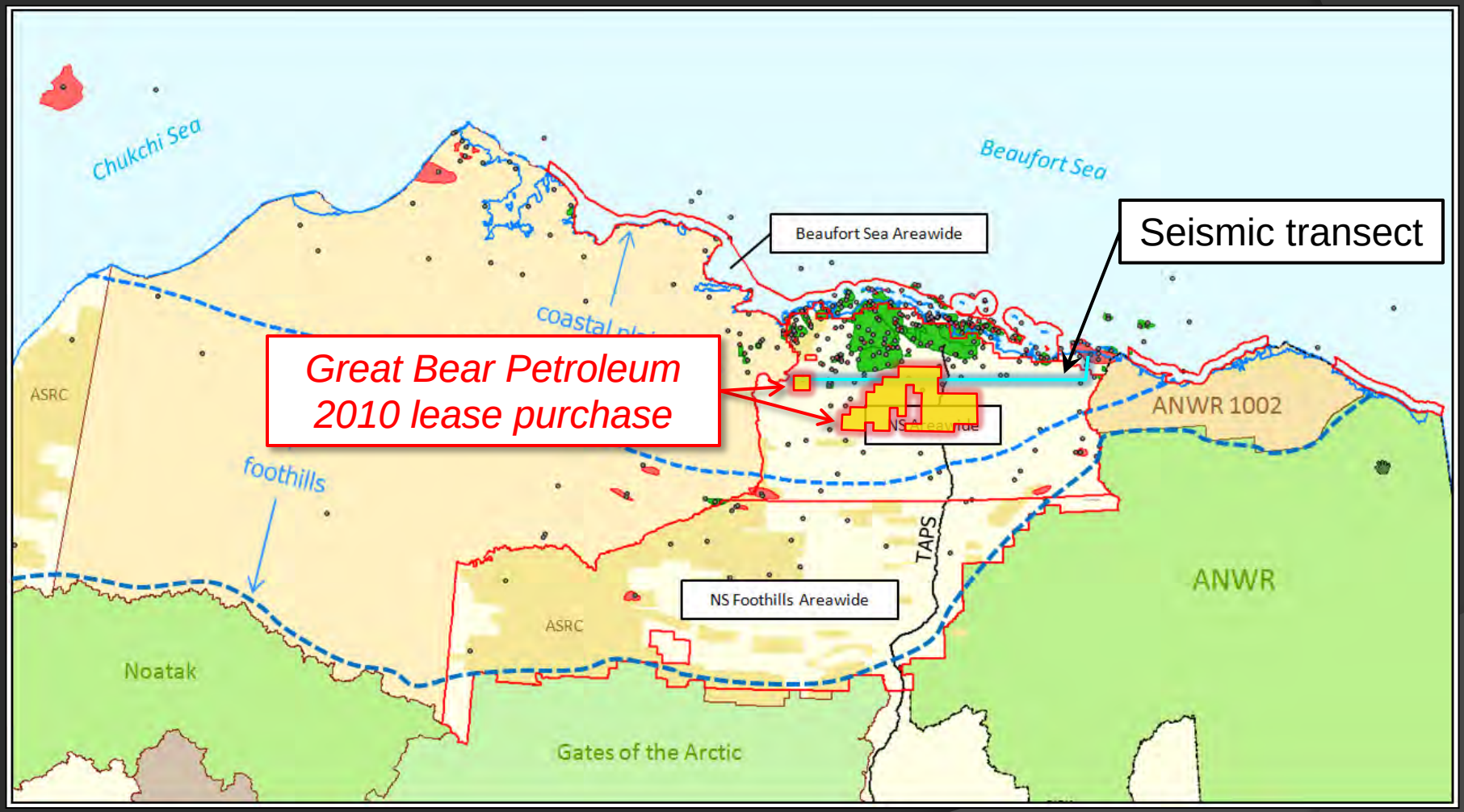
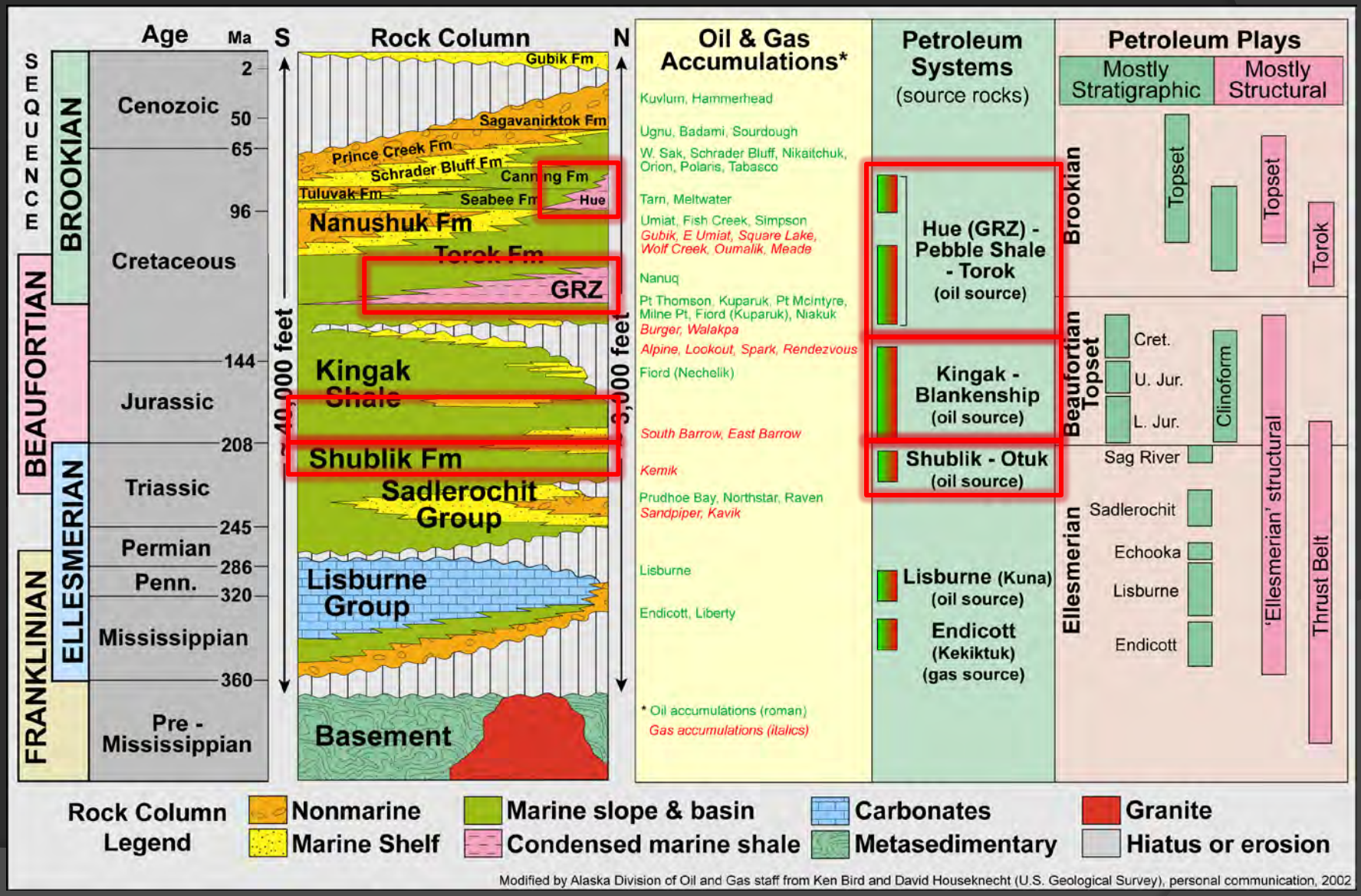
North Slope Region



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

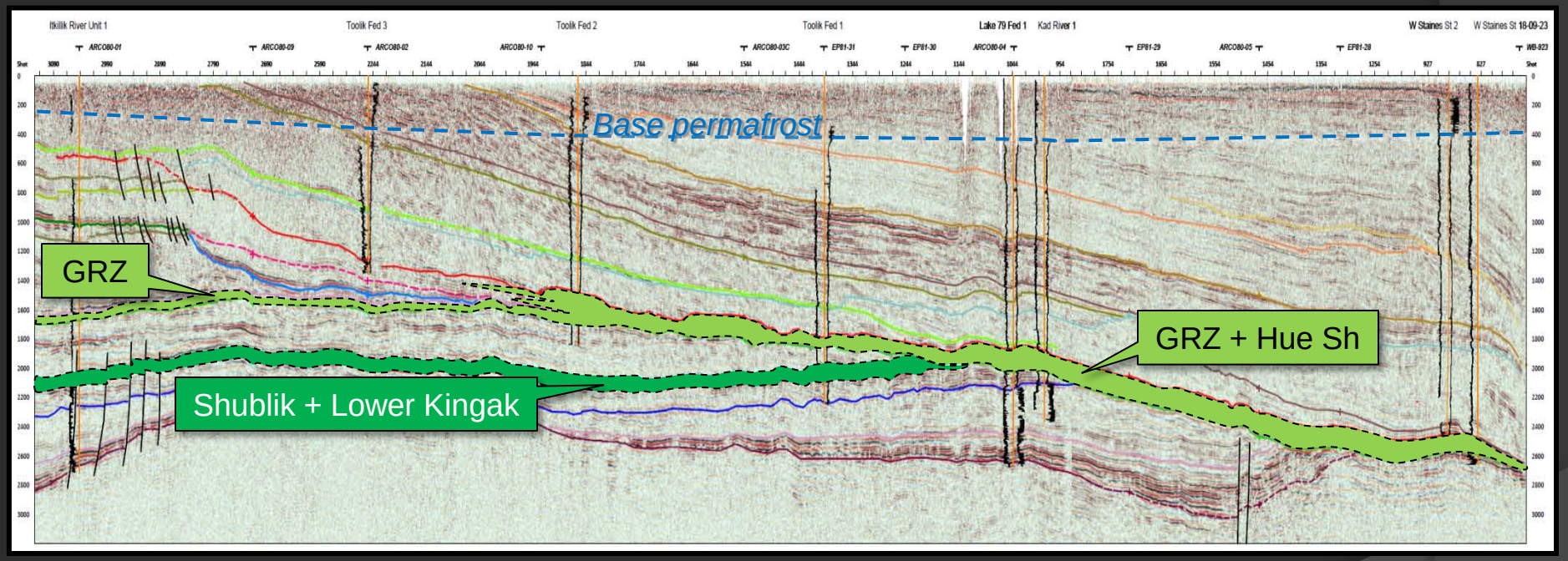
Major North Slope Oil Source Rocks

younger & shallower ⟷ *older & deeper*

- 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)
  - Phospatic 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

West East



- 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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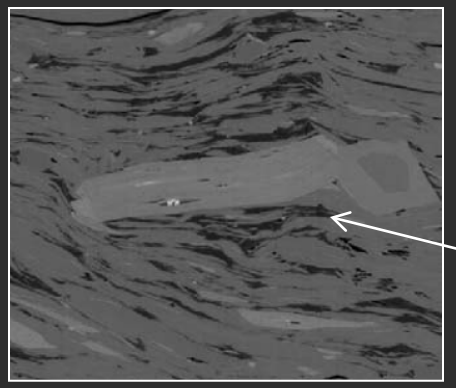
Key Geologic Factors -- Shale Resource Plays

- 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)

Resource Assessments

Source rock systems

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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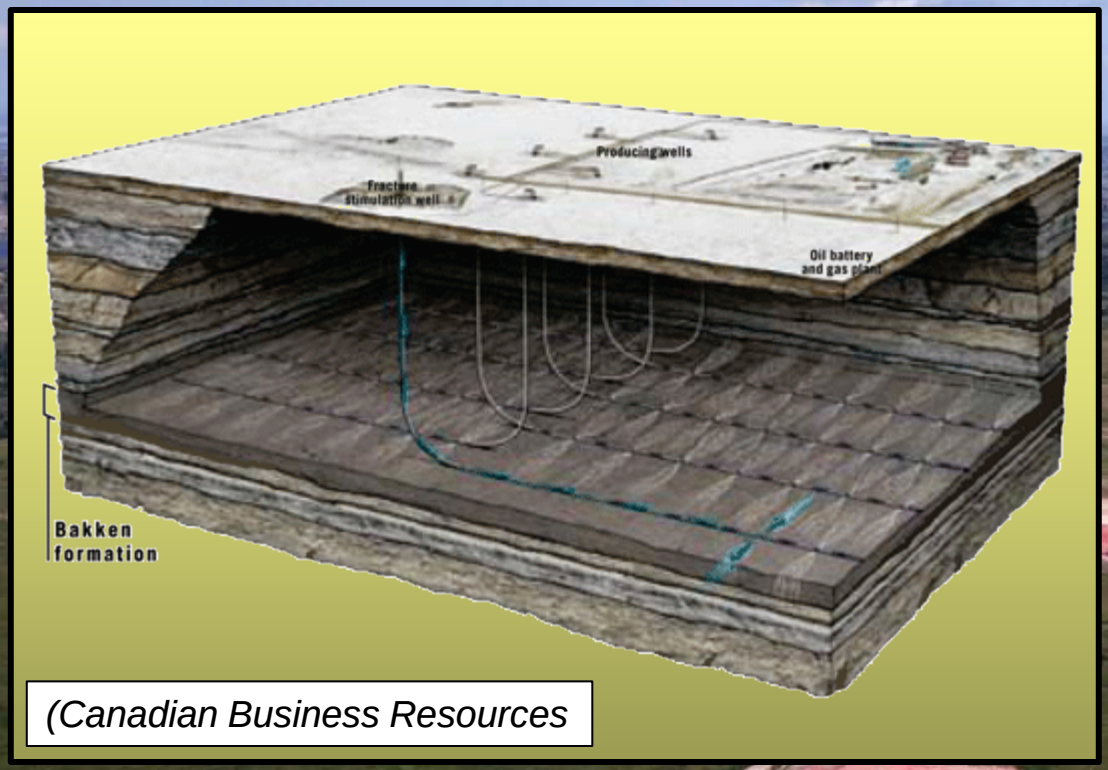
Close Well Spacing, Many Pads



(Canadian Business Resources

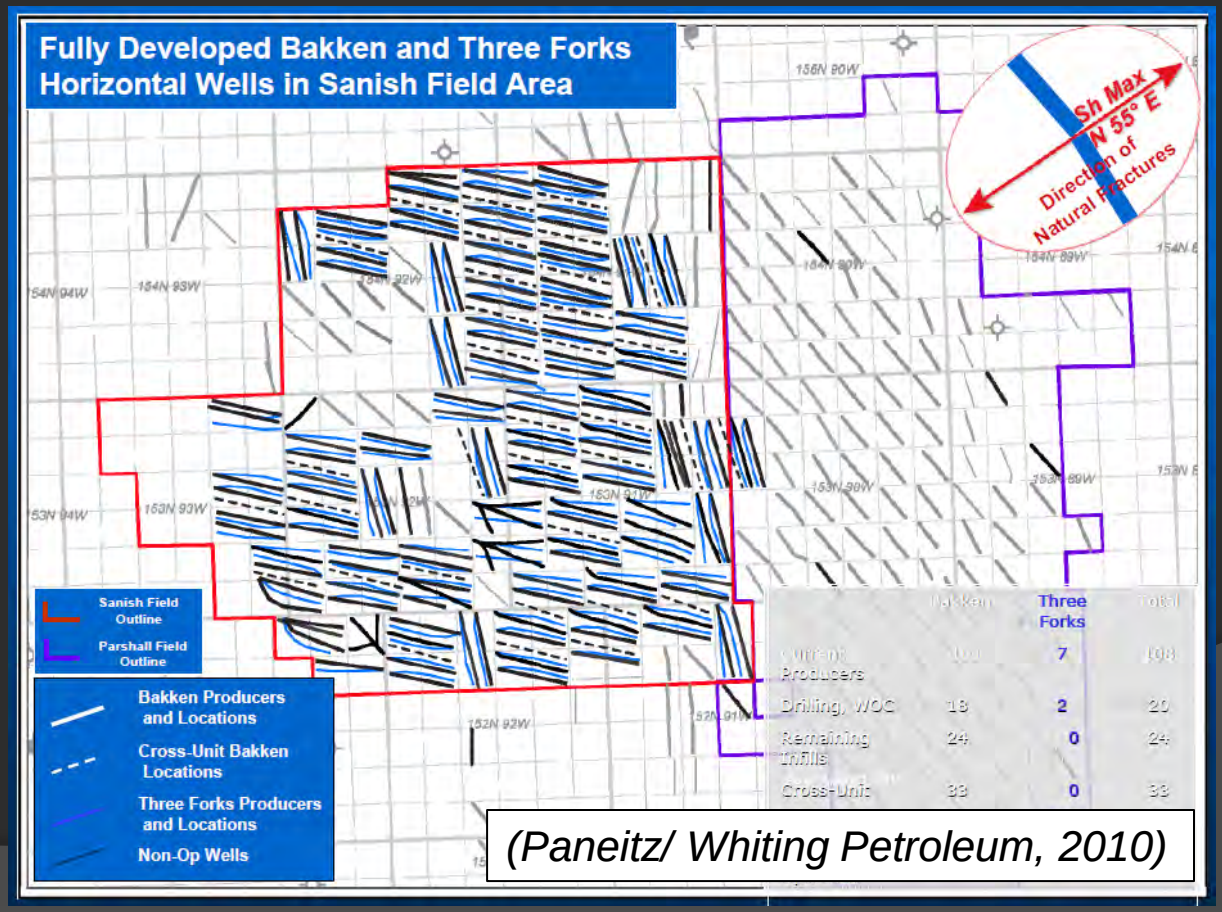
70 acres total surface impact (14 pads, 5 acres each) → 17,920 acres of subsurface development (2 mile-long laterals on each side of road times 7 miles length times 640 acres/mi^2)

(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?

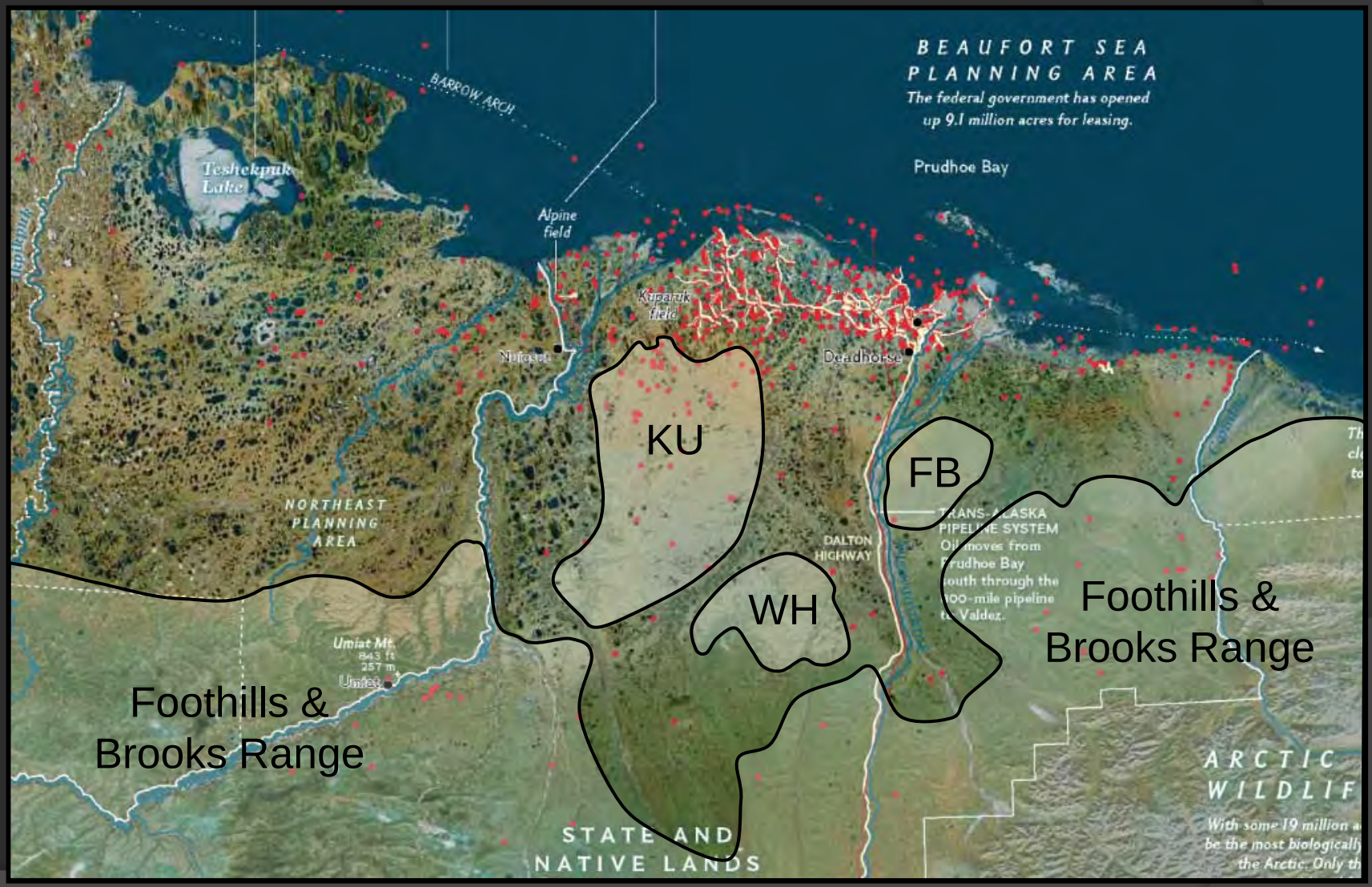
  Frac jobs for horizontal producers in L48 shale plays consume 1 to 5.5 million gallons of water (and millions of pounds of sand) per well, depending on rock properties, number of stages pumped, etc.
  (For comparison, ice roads require 1-1.5 million gallons per mile.)

- 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

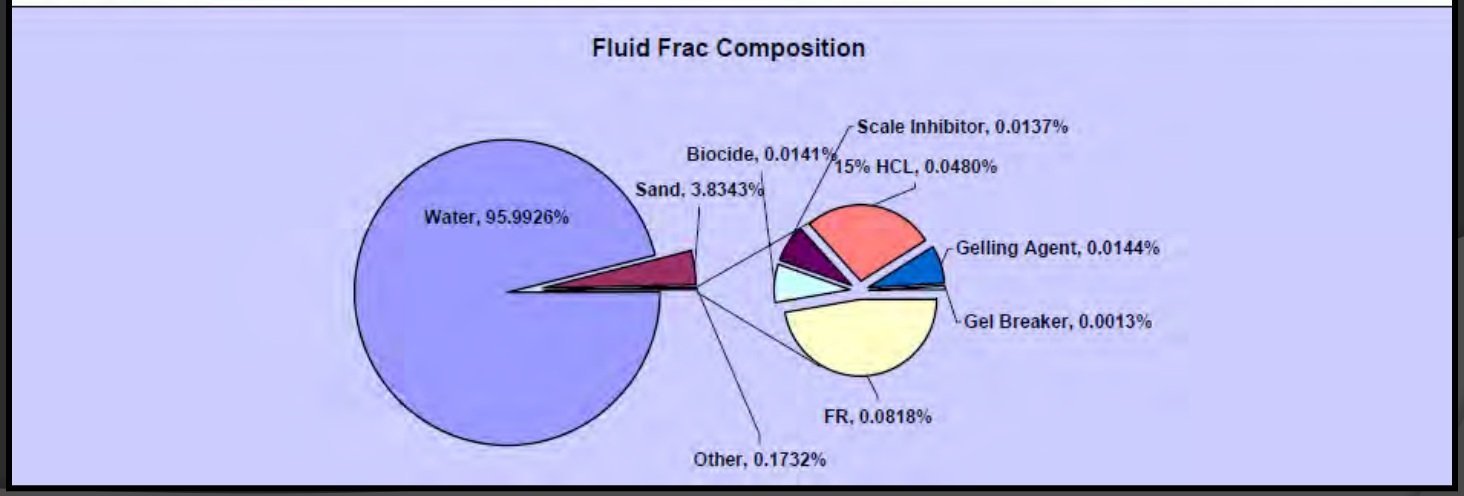


(National Geographic, 2006; http://ngm.nationalgeographic.com/ngm/0605/feature1/map.html)

Frac Fluids

Composition for a 16-stage West Virginia Marcellus Shale well

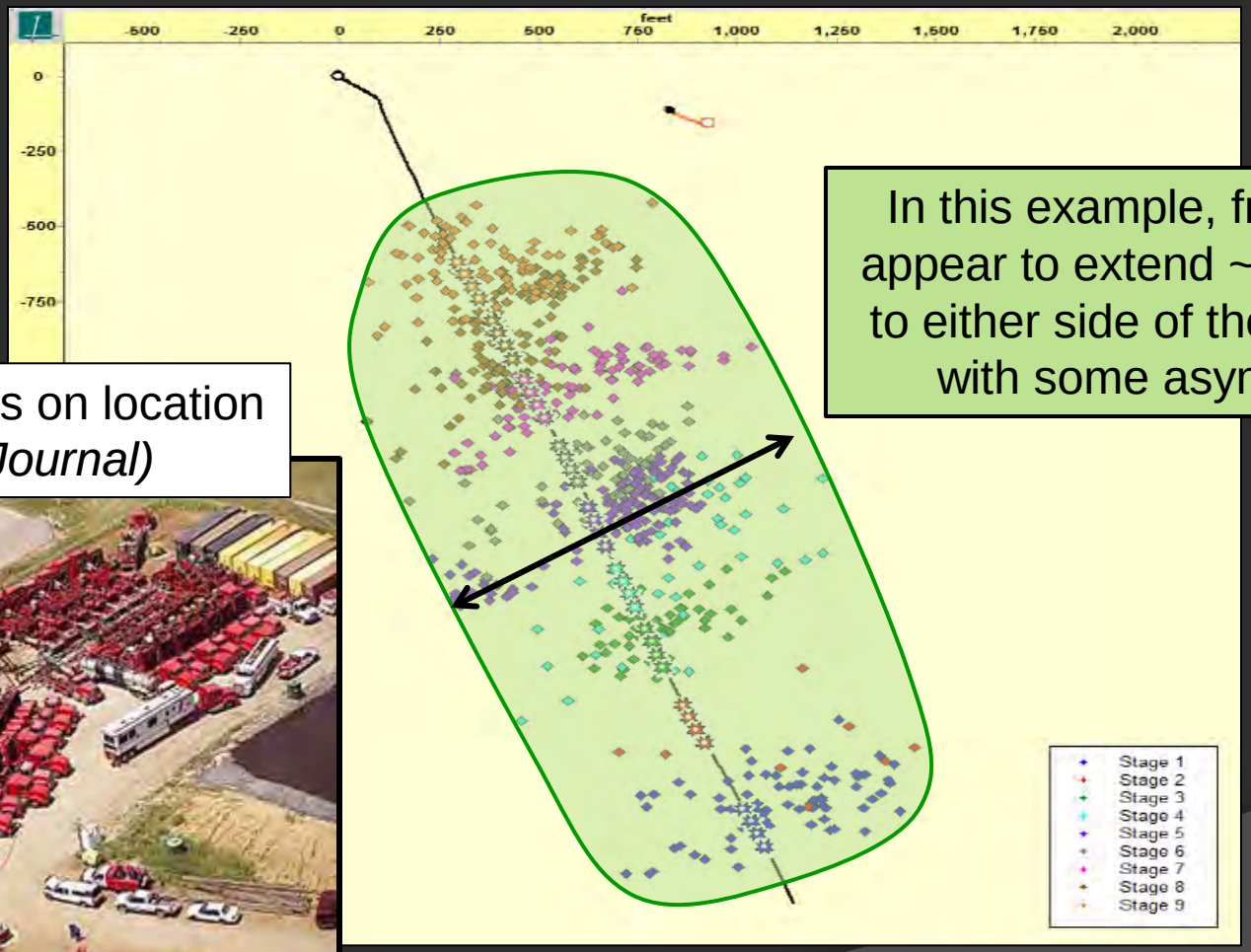
Product Name	Additive	Purpose	Use and Dilution	Actual Volume	Overall %
Water	Carrier Fluid	Creates fracture network in shale and carry sand to the formation	Approximately 4 million gallons per well	7,416,822 gal	95.9926%
Sand	Sand	Enable fractures to remain open and allow gas to escape into the wellbore	Approximately 4 million pounds per well	296,255 gal	3.8343%
FR	Friction Reducer	Reduces friction between pipe and fluid	Diluted at one gallon per 1,000 gallons of water	6,318 gal	0.0818%
Biocide	Antimicrobial Agent	Eliminates bacteria in water sources	Diluted at one-half gallon per 1,000 gallons of water	1,089 gal	0.0141%
Scale Inhibitor	Scale Inhibitor	Prevents scale deposits	Diluted at one gallon per 1,000 gallons of water	1,057 gal	0.0137%
15% HCL	Acid	Dissolves cement and minerals in the perforations (non-diluted)	250 gallons per stage (non-diluted chemicals)	3,709 gal	0.0480%
Gelling Agent	Viscosifier	Adds viscosity to the fluid	Diluted at five gallons per 1,000 gallons of water	1,109 gal	0.0144%
Gel Breaker	Breaker	Reduces viscosity of fluid	Diluted at one-half gallons per 1,000 gallons of water	98 gal	0.0013%



Source: EQT Energy, 2011 (http://www.eqt.com/docs/pdf/FluidCompositions/Well512456.pdf)

Frac Jobs

Where are the fractures and how far do they extend?



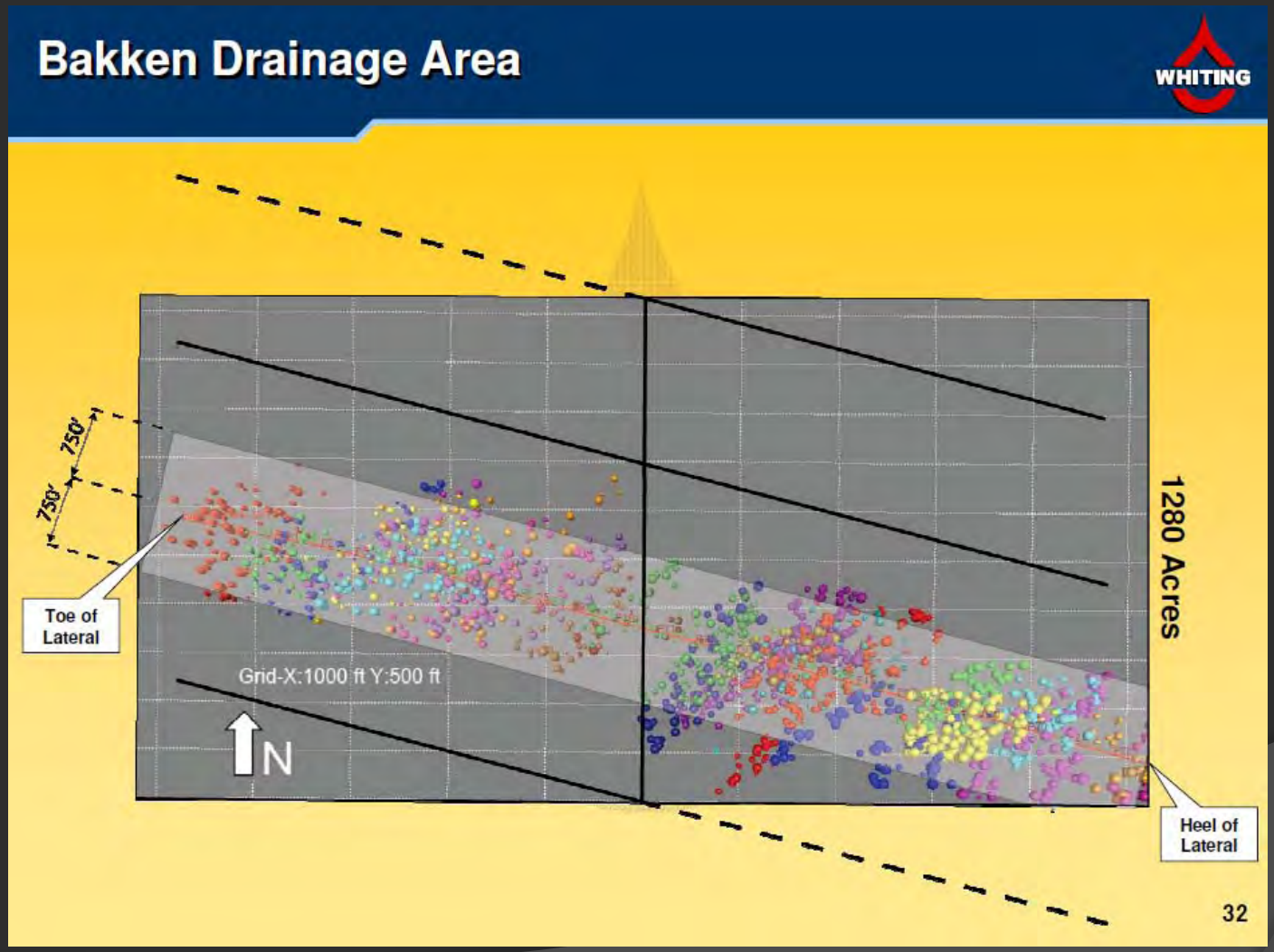
In this example, frac wings appear to extend ~450-550 ft to either side of the wellbore with some asymmetry

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?

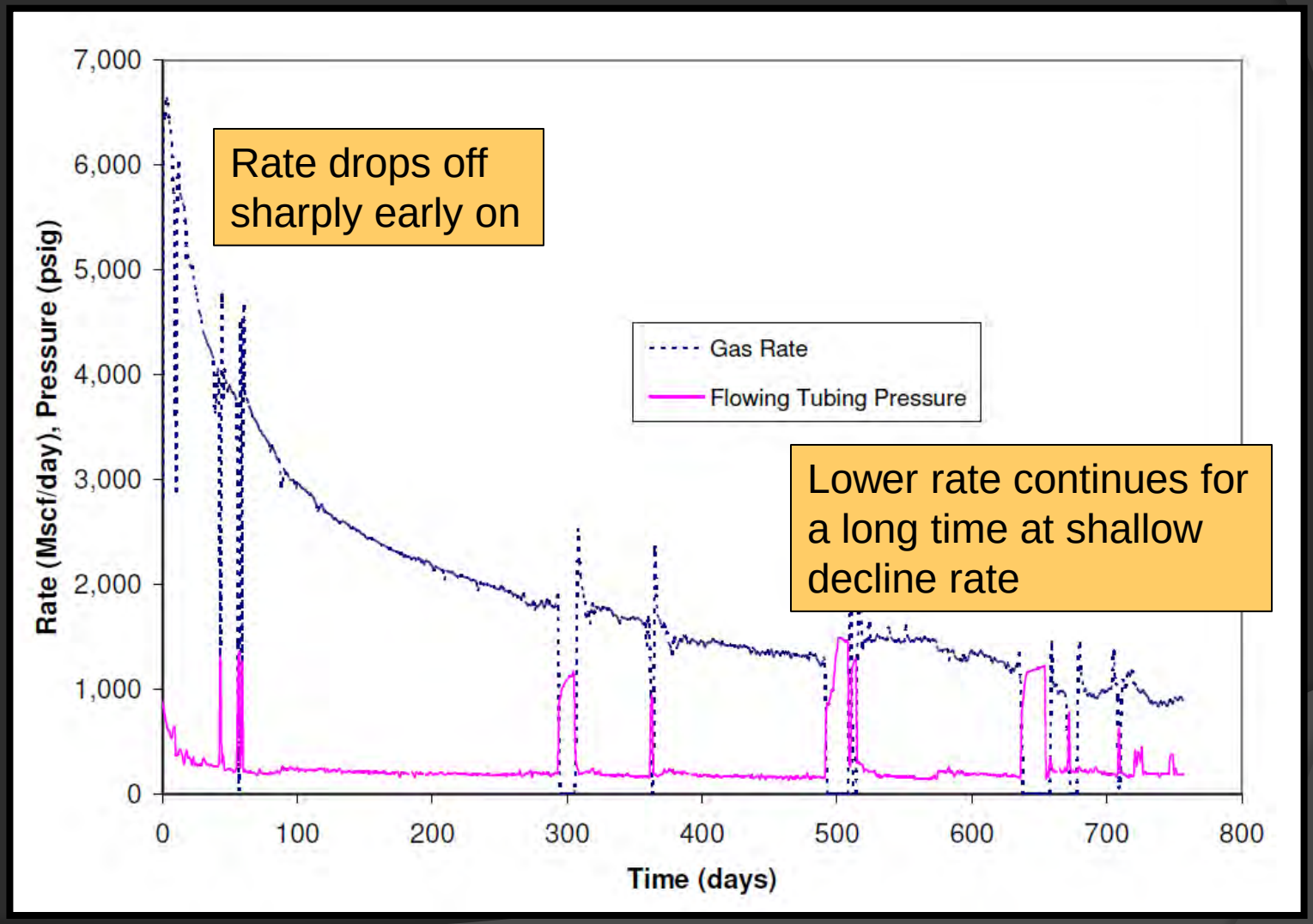


24-stage Bakken Formation frac

(Whiting Petroleum, 2011)

Single well flow rate over time

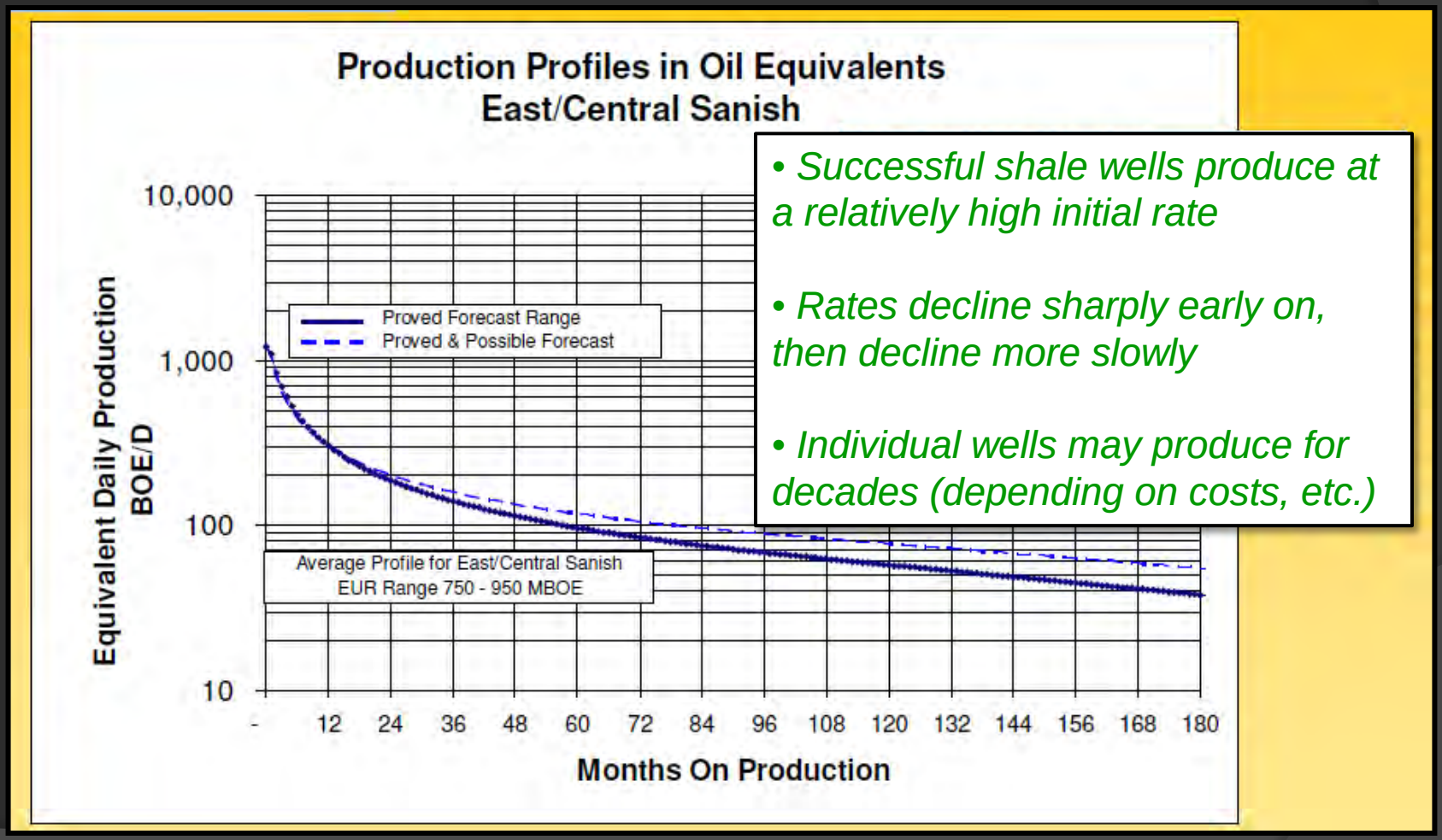
Shale gas well example



(Bello, 2009)

Single well flow rate over time

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



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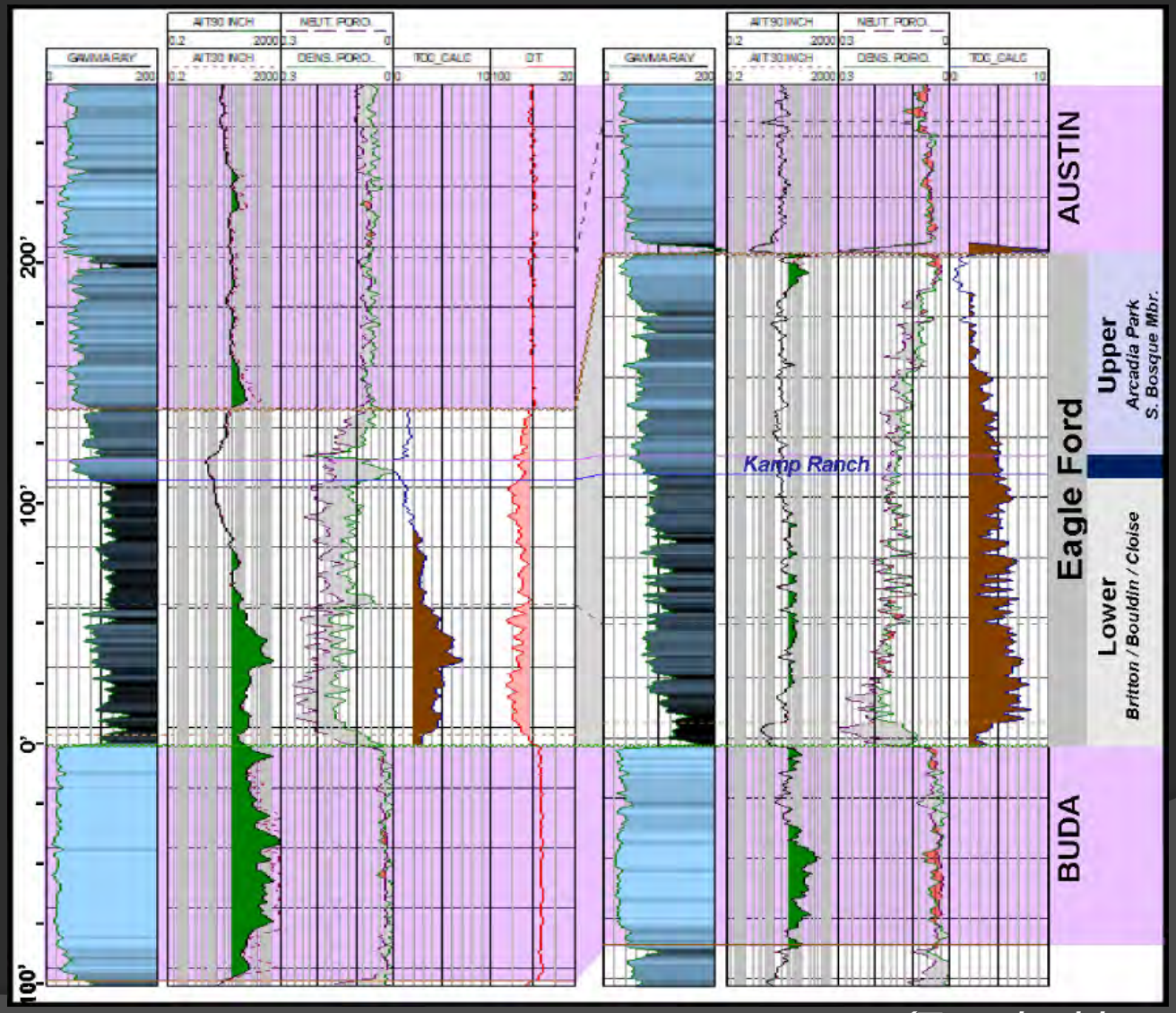
Texas Analogue (?)

Upper Cretaceous Eagle Ford Shale (Boquillas Fm)

Texas Analogue (?)

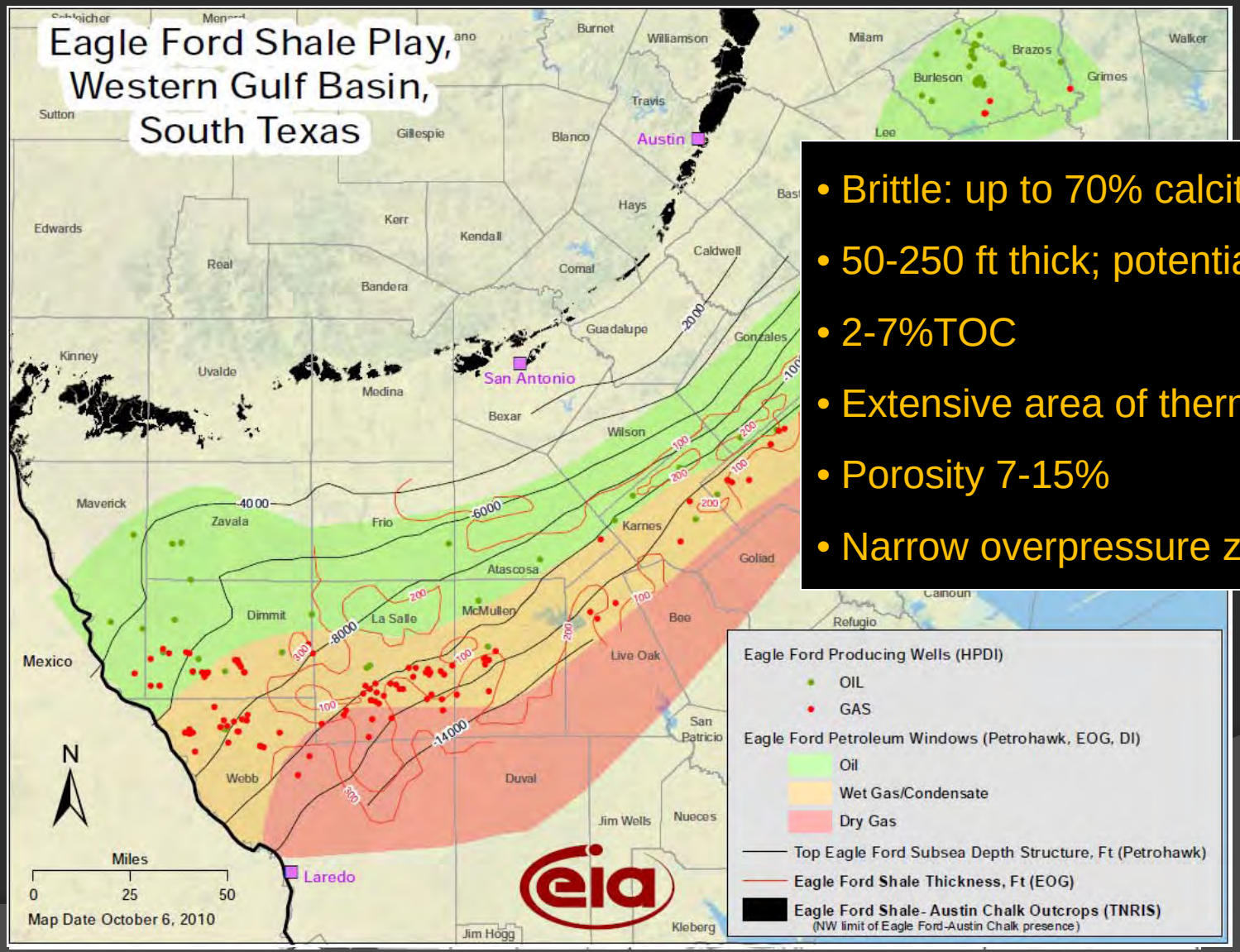
Upper Cretaceous Eagle Ford Shale



(Treadgold and Nicklin, 2011)

Texas Analogue (?)

Upper Cretaceous Eagle Ford Shale

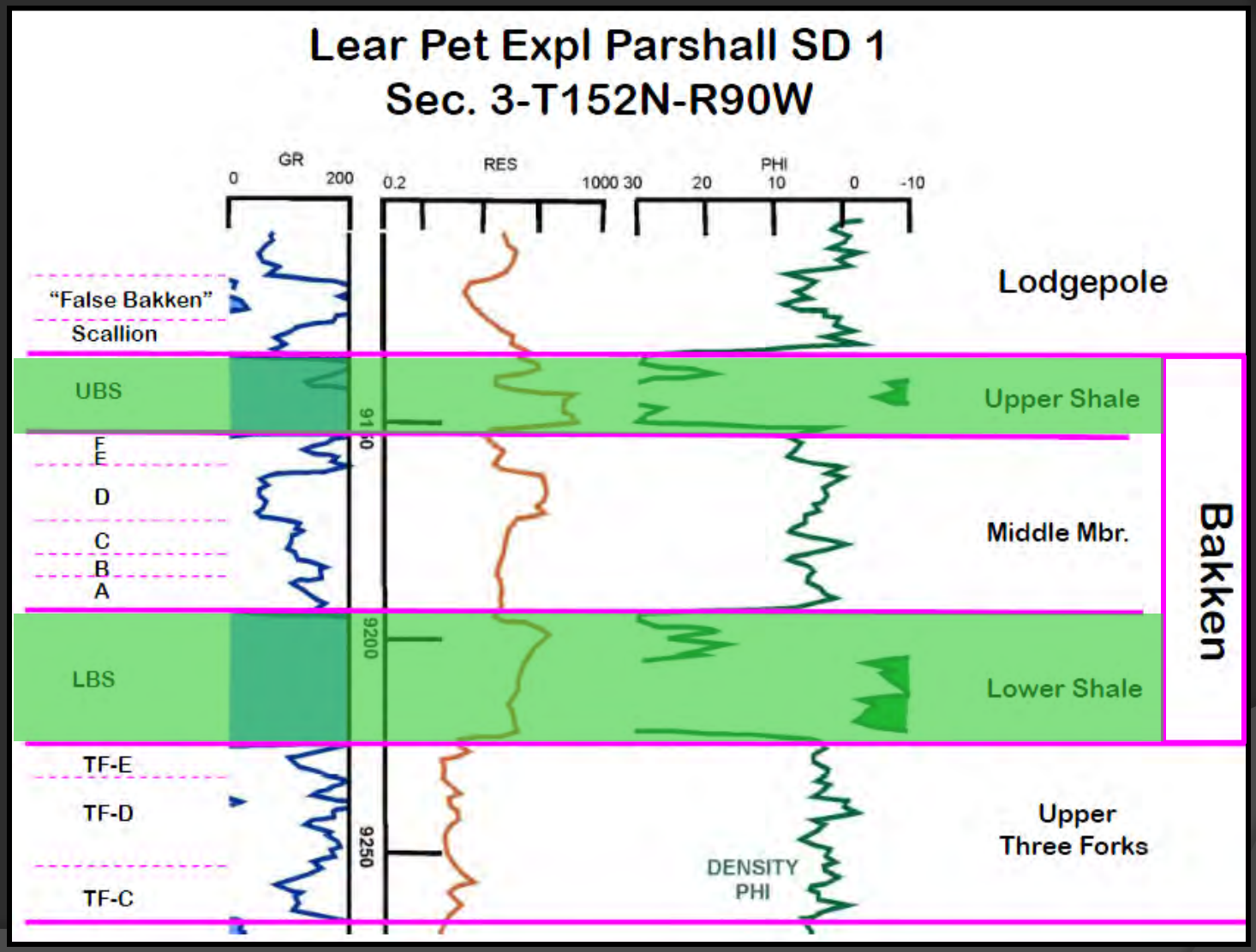


- Brittle: up to 70% calcite
- 50-250 ft thick; potentially all net pay
- 2-7%TOC
- Extensive area of thermal maturity
- Porosity 7-15%
- Narrow overpressure zone

(Energy Information Administration, 2010)

North Dakota Analogue (?)

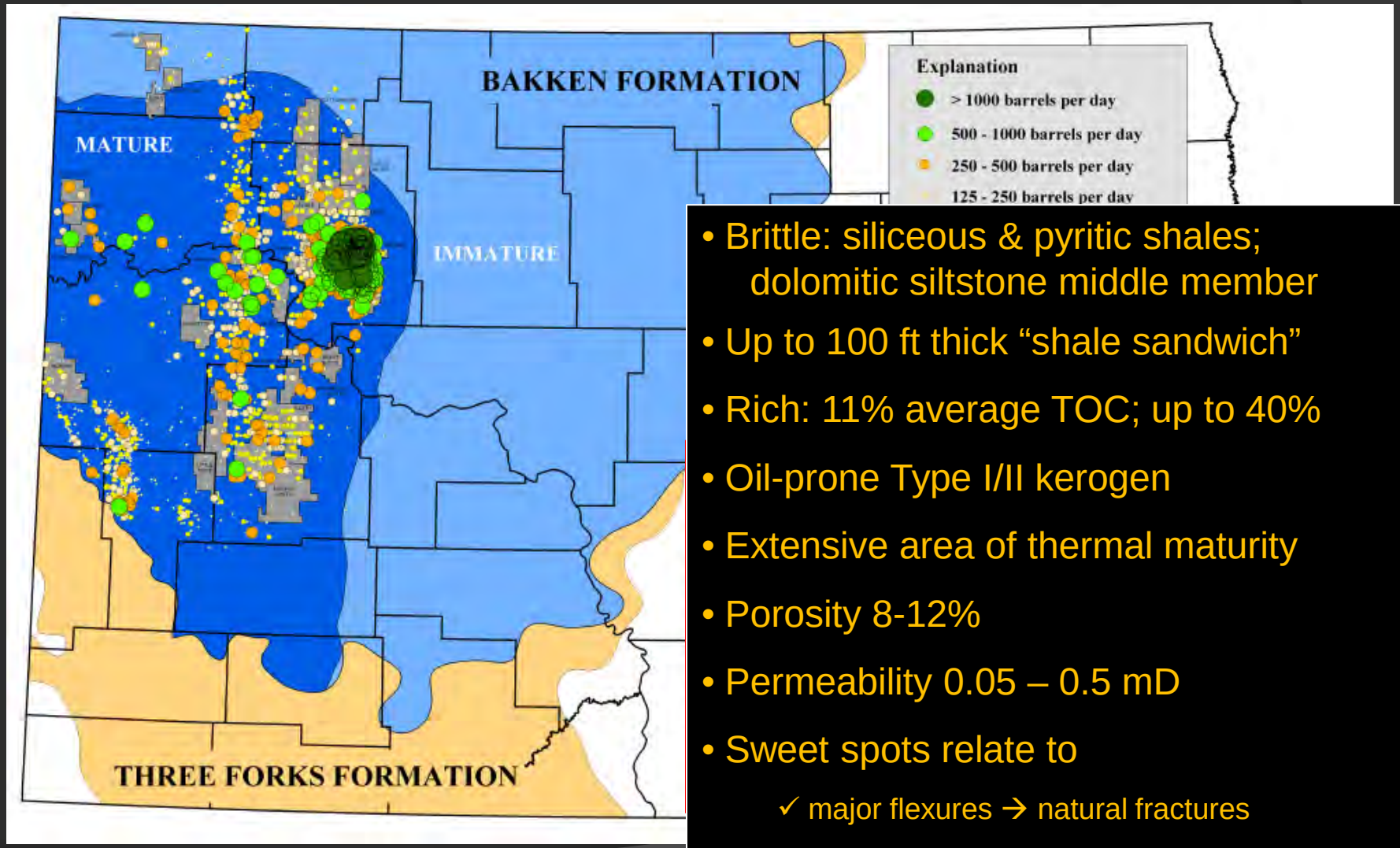
Devonian-Mississippian Bakken Fm – shale sandwich



(modified after Sonnenberg, 2011)

North Dakota Analogue (?)

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



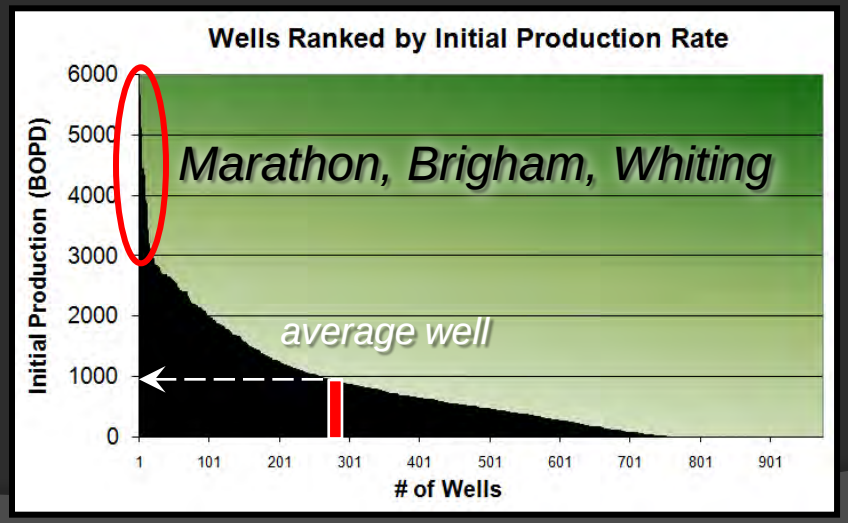
- Brittle: siliceous & pyritic shales; dolomitic siltstone middle member
- Up to 100 ft thick "shale sandwich"
- Rich: 11% average TOC; up to 40%
- Oil-prone Type I/II kerogen
- Extensive area of thermal maturity
- Porosity 8-12%
- Permeability 0.05 – 0.5 mD
- Sweet spots relate to
  - ✓ major flexures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

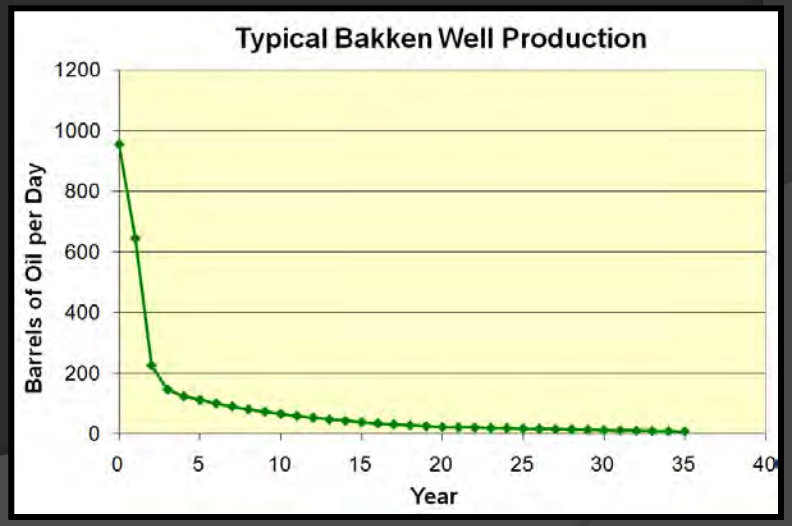
(Nordeng, 2010; Nordeng and others, 2010)

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%





(courtesy Lynn Helms NDIC, DMR, 2011)

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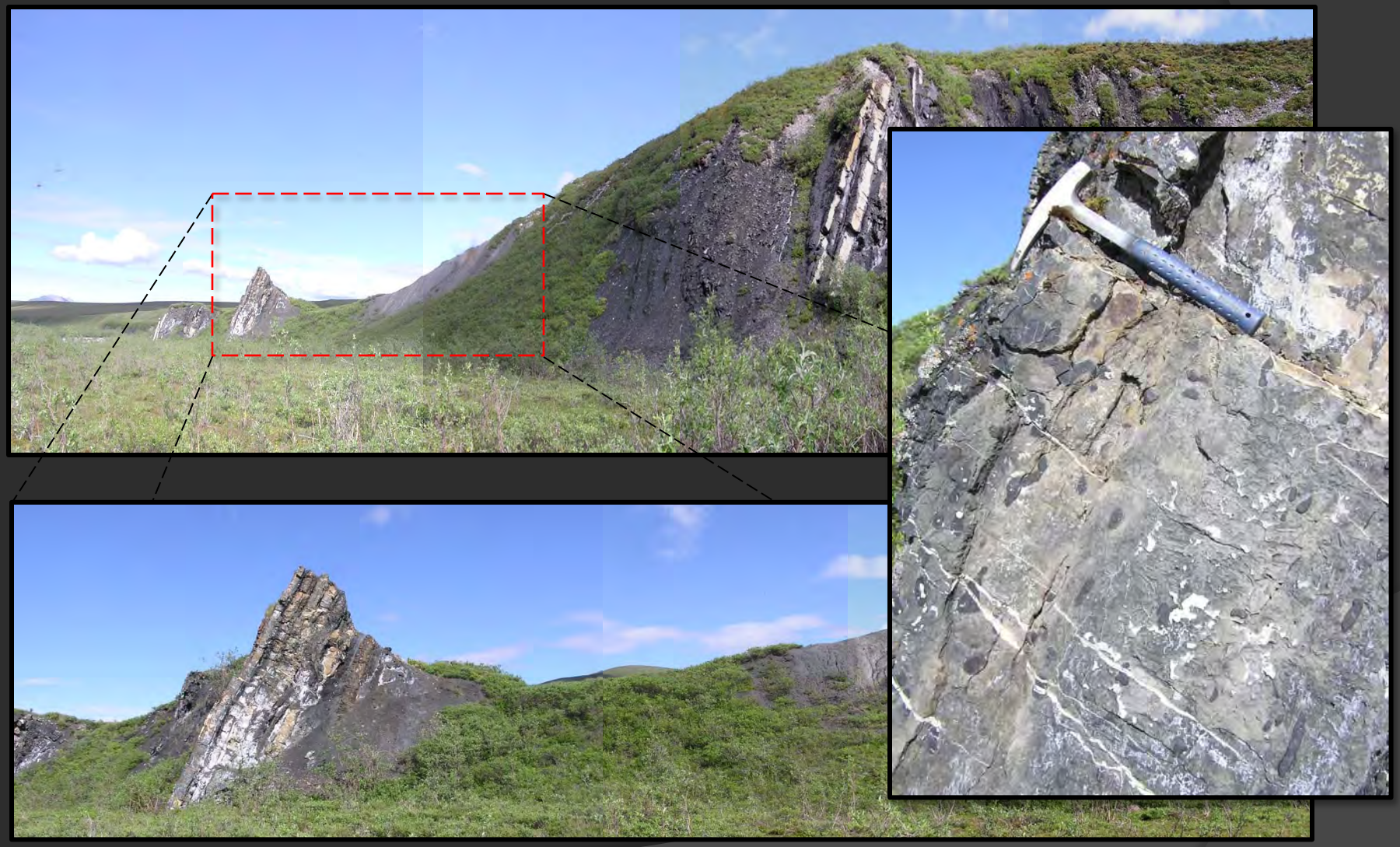
Shublik Formation

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

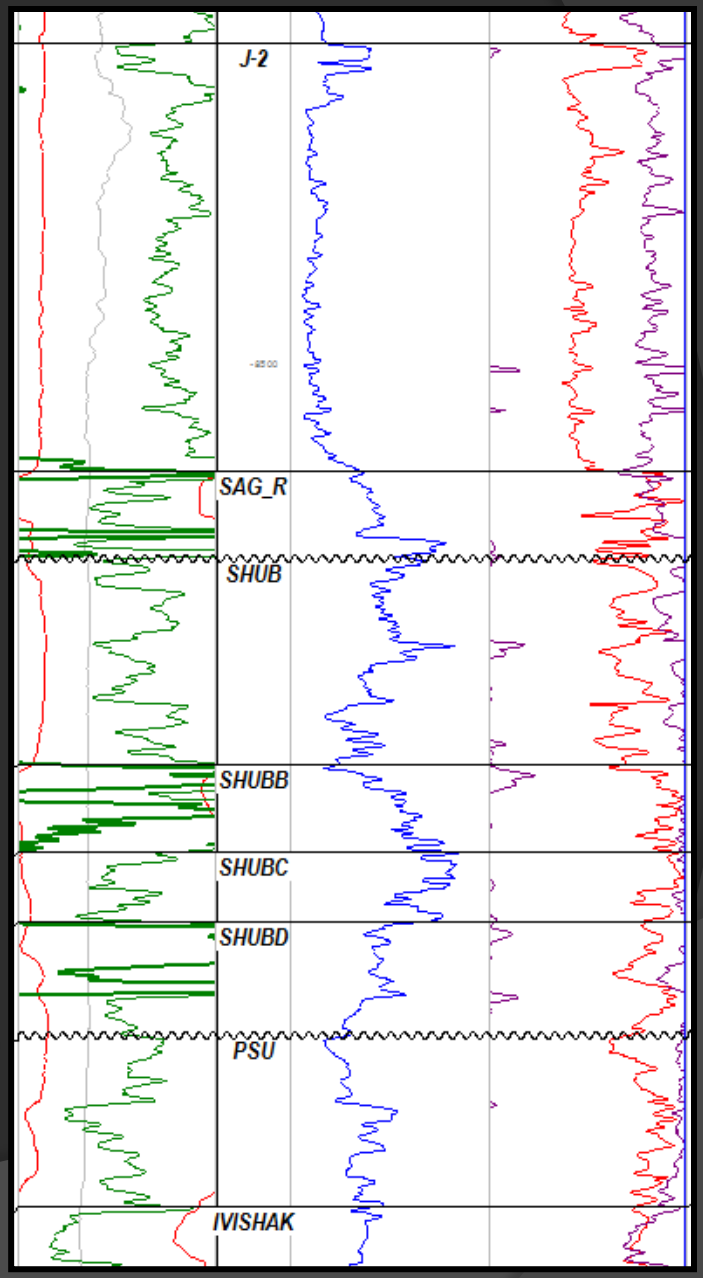
Zone B

Zone C

Zone D

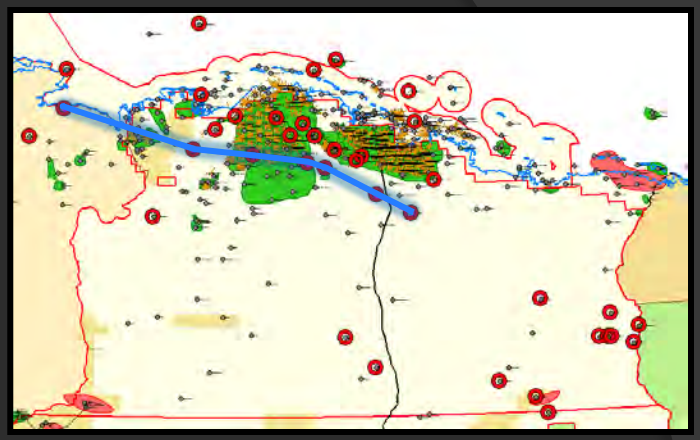
Sadlerochit Gp

Rock Flour 1

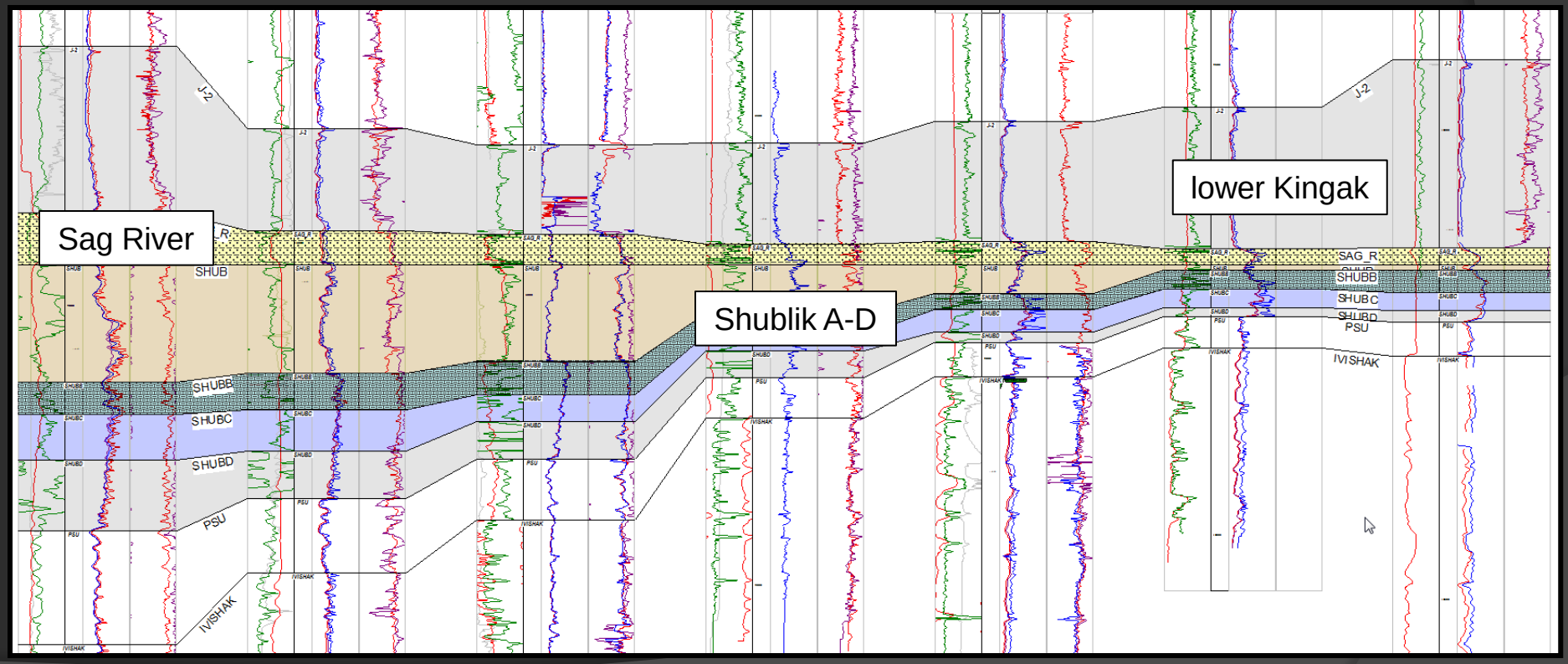


Shublik Formation

Well logs and zonal correlations



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



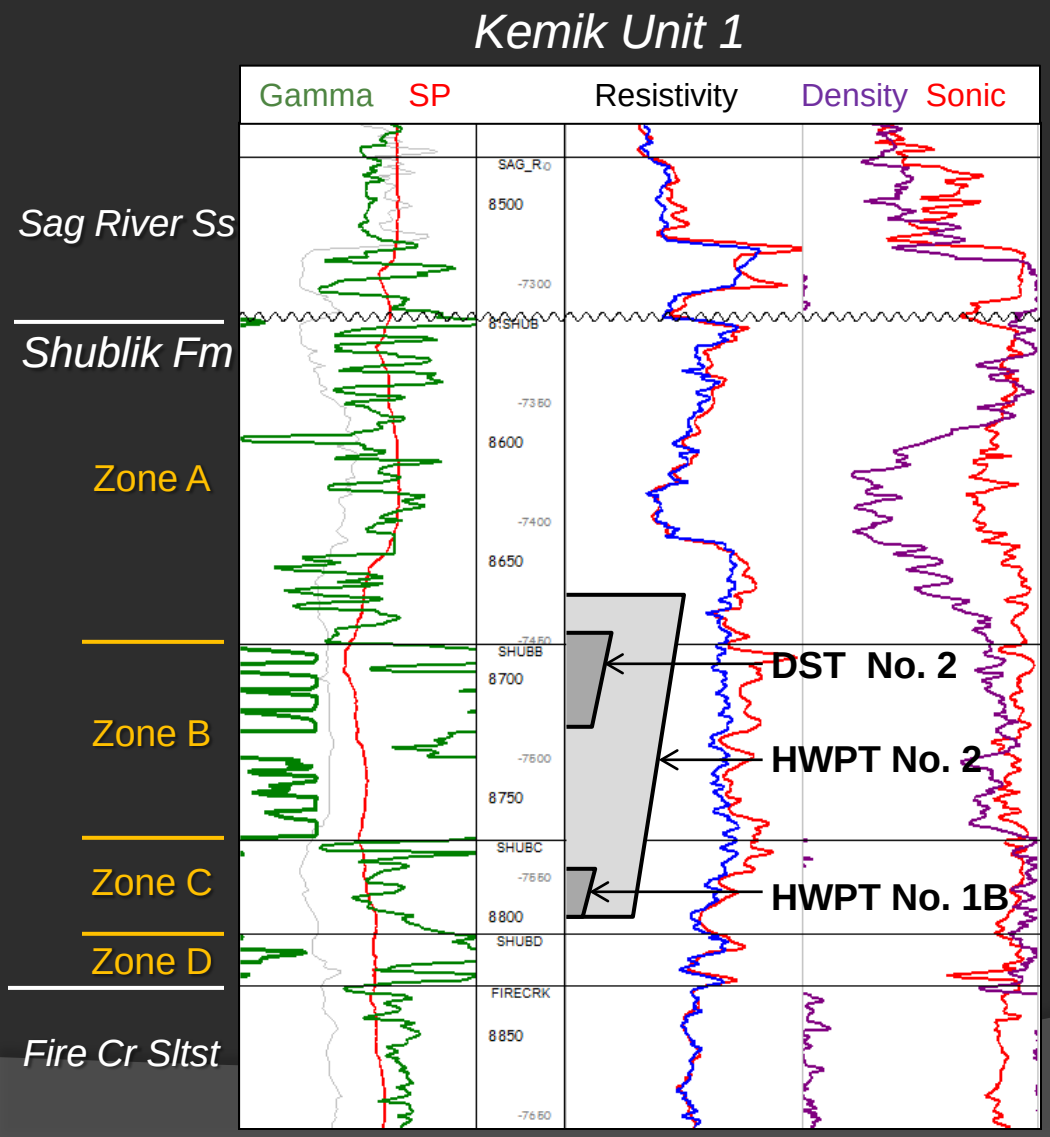
(Decker, unpublished data, 2011)

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

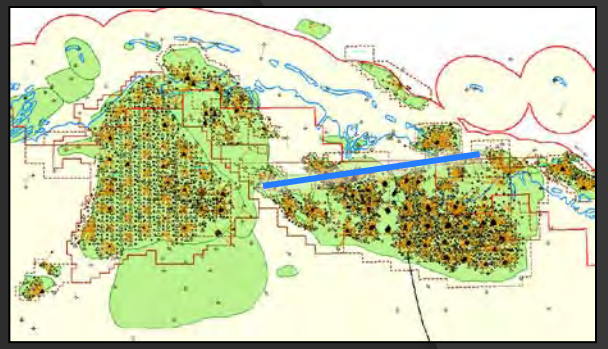
Shublik A-B: ***12 MMCFD (AOF?)***

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

Gamma SP Resistivity Density Sonic

Gamma SP Resistivity Density Sonic

Sag River Ss

Shublik Fm

zonal correlations uncertain

Ivishak Fm

IVISHAK

SHUB

SHUBB

SHUBC

SHUBD

8800

8850

8900

8950

IVISHAK

10200

10250

10300

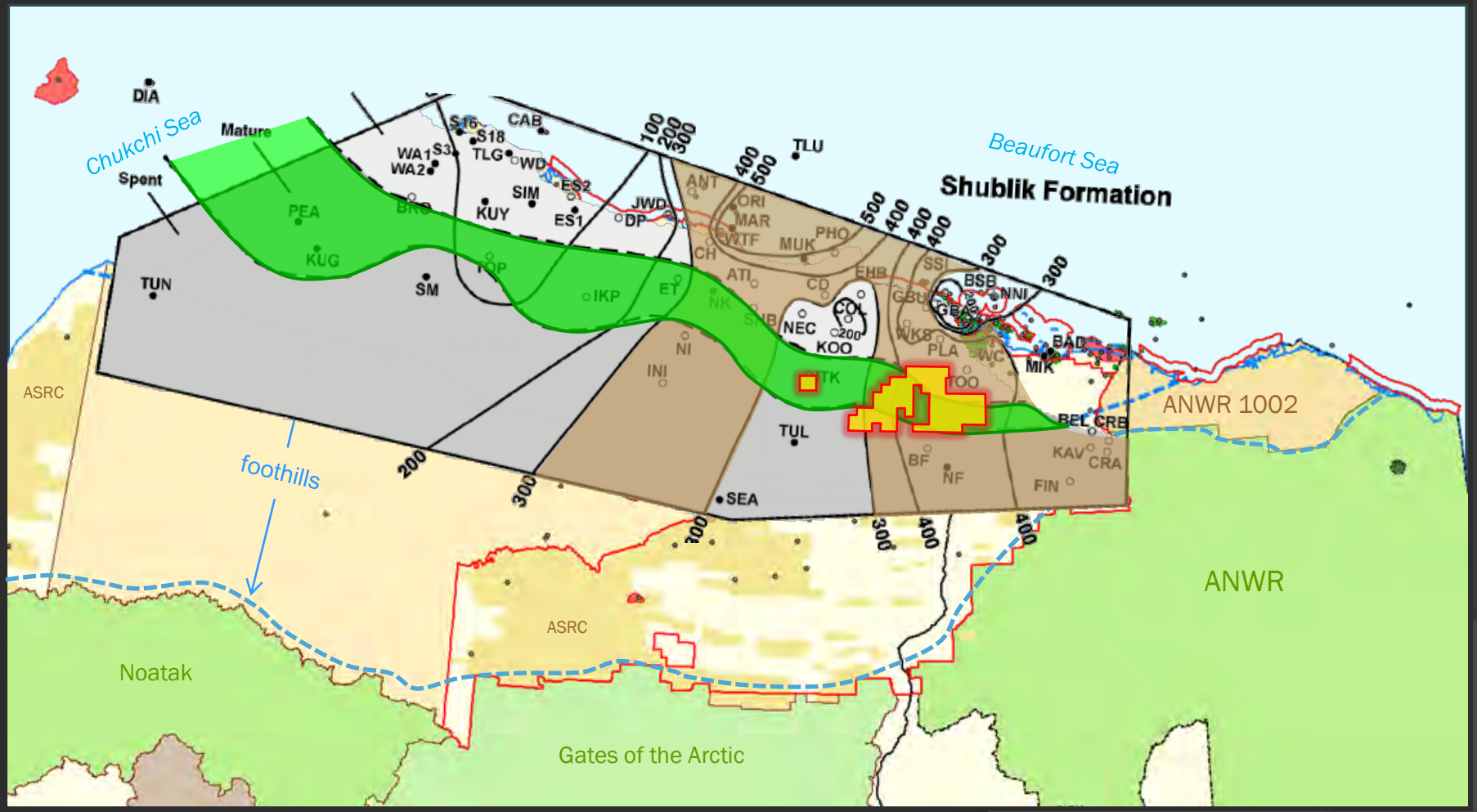
10350

2540 BOPD

1152 BOPD, 7/8" choke

Shublik Formation

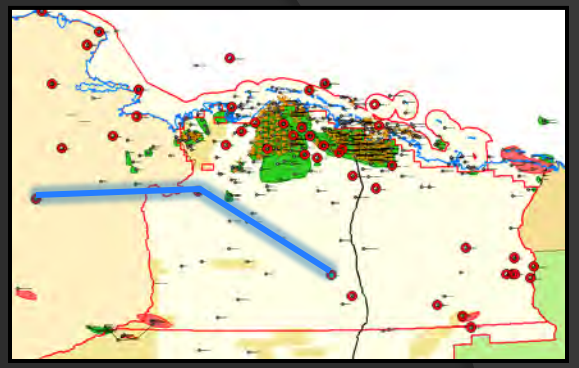
Hydrogen Index and Thermal Maturity



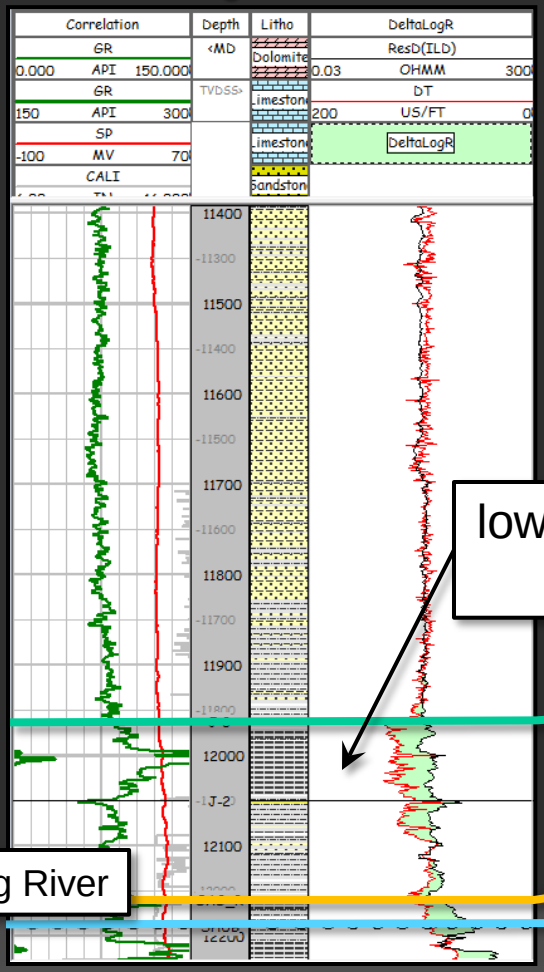
(overlay figure from Peters and others, 2006)

Lower Kingak Formation

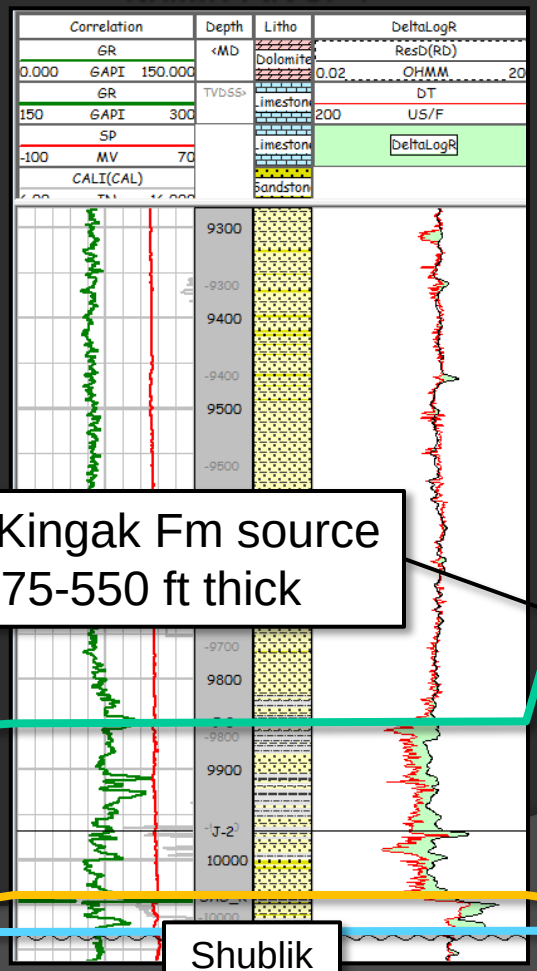
Δ Log R source rock screening



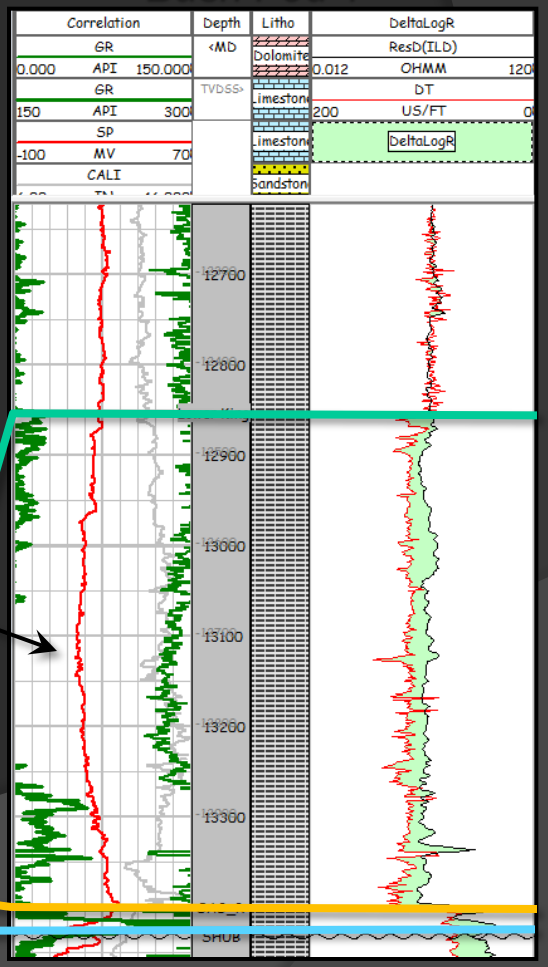
Inigok 1



Itkillik River 1



Bush Fed 1



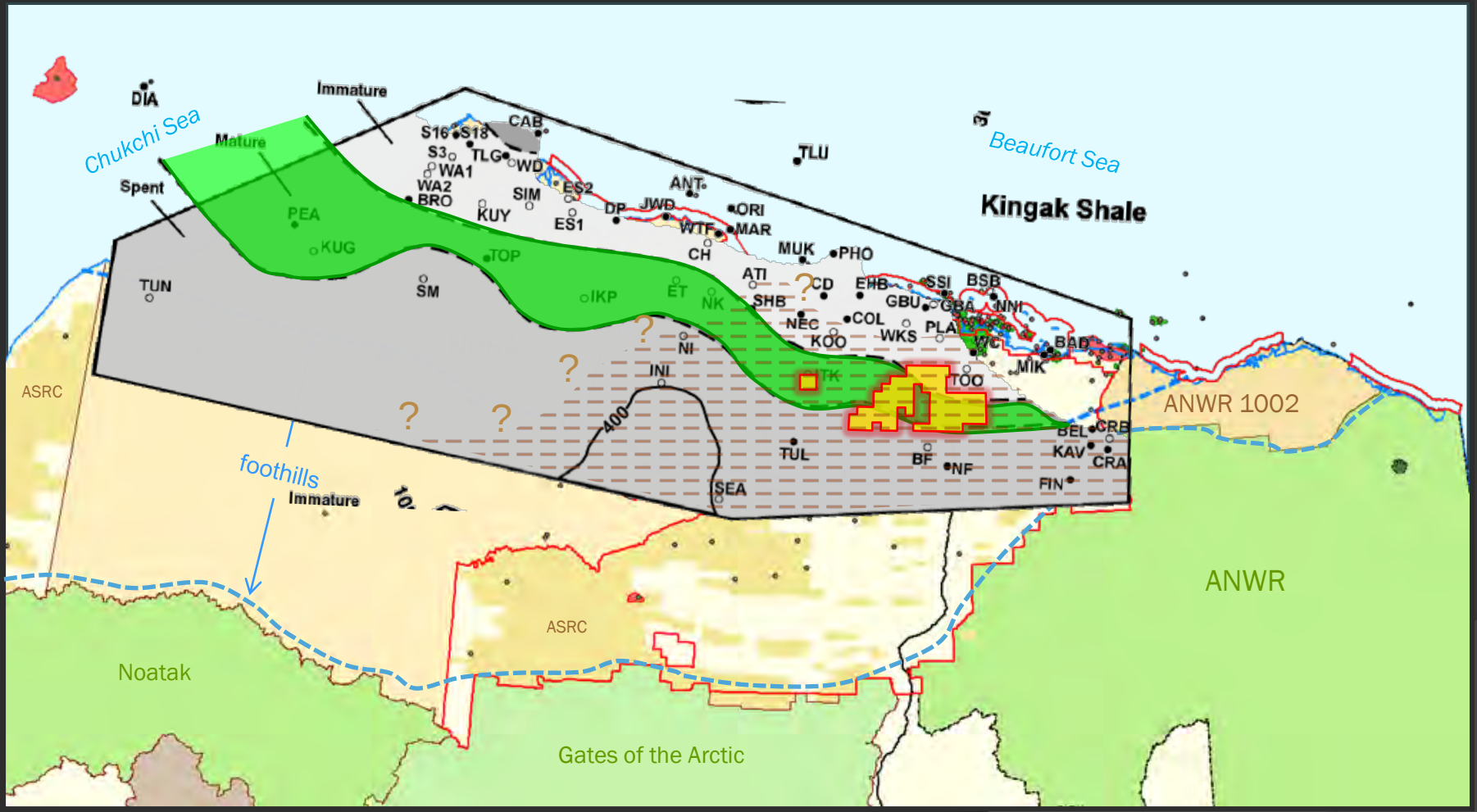
lower Kingak Fm source
~175-550 ft thick

Sag River

Shublik

Lower Kingak Formation

Hydrogen Index (??) and Thermal Maturity



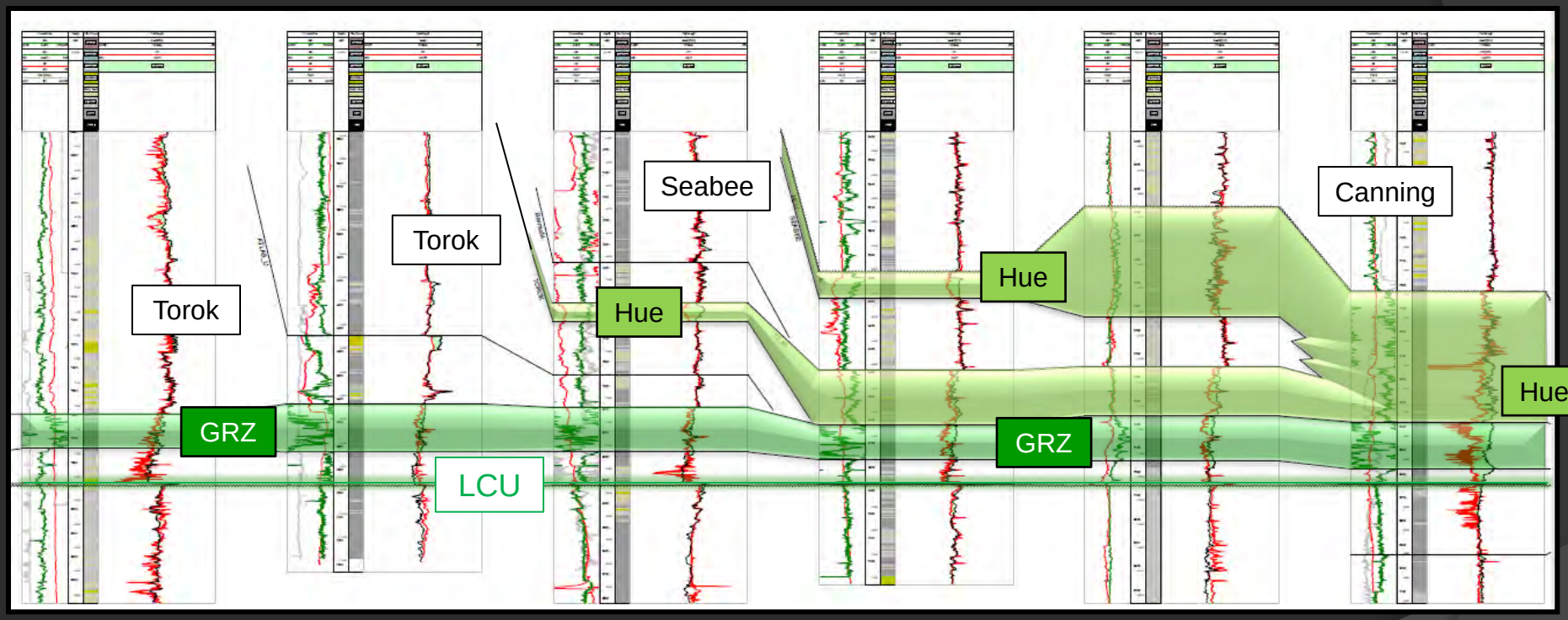
(overlay figure from Peters and others, 2006)

Hue Shale/GRZ

Type section outcrops at Hue Creek, ANWR

Hue Shale/GRZ

Correlation Section and Δ Log R Total Organic Content estimates

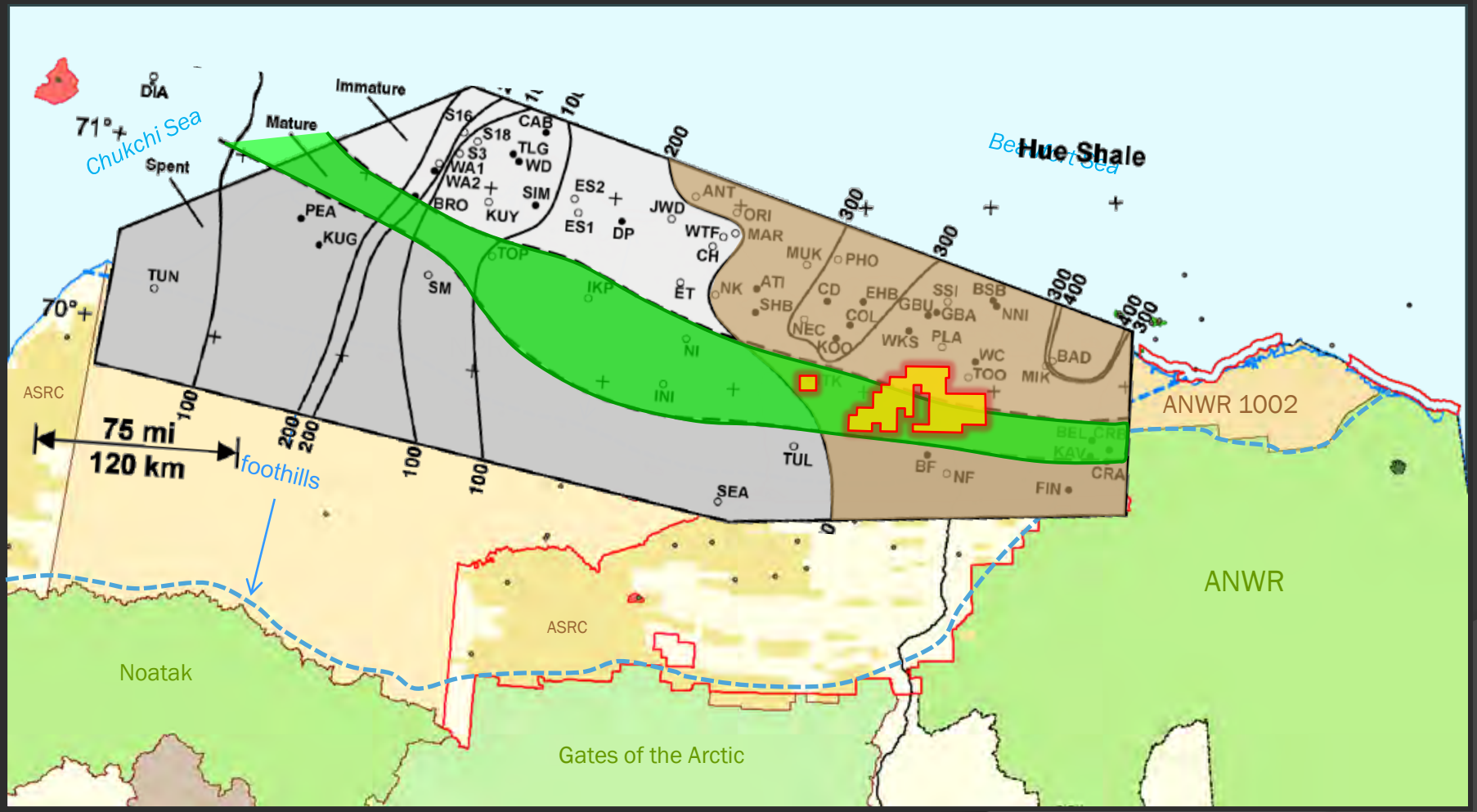


Δ Log R calculated TOC estimates	Itkillik R 1	Atlas 1	Narvaq 1	W Sak 26	Toolik 2	Hemi Spr 3
Hue Sh		4.9%		2.6%	3.1%	4.8% (?)
GRZ	2.6%	2.4%	1.6%	5.0%	3.1%	10.3% (?)

(Decker, unpublished data, 2009)

Hue Shale/GRZ

Average Hydrogen Index and Thermal Maturity



(overlay figure from Peters and others, 2006)

Source Rock Comparison

Geologic characteristics

	Bakken	Eagle Ford	Shublik	L. Kingak	Hue/GRZ
Total Organic Carbon	10% avg	2-7%	2-3% 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°	24-45°	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)

Talk Outline

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

North Alaska 2011 Areawide Lease Sales

Rescheduled to December 7-- All available unleased State tracts

2011 North Alaska Areawide Lease Sales

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

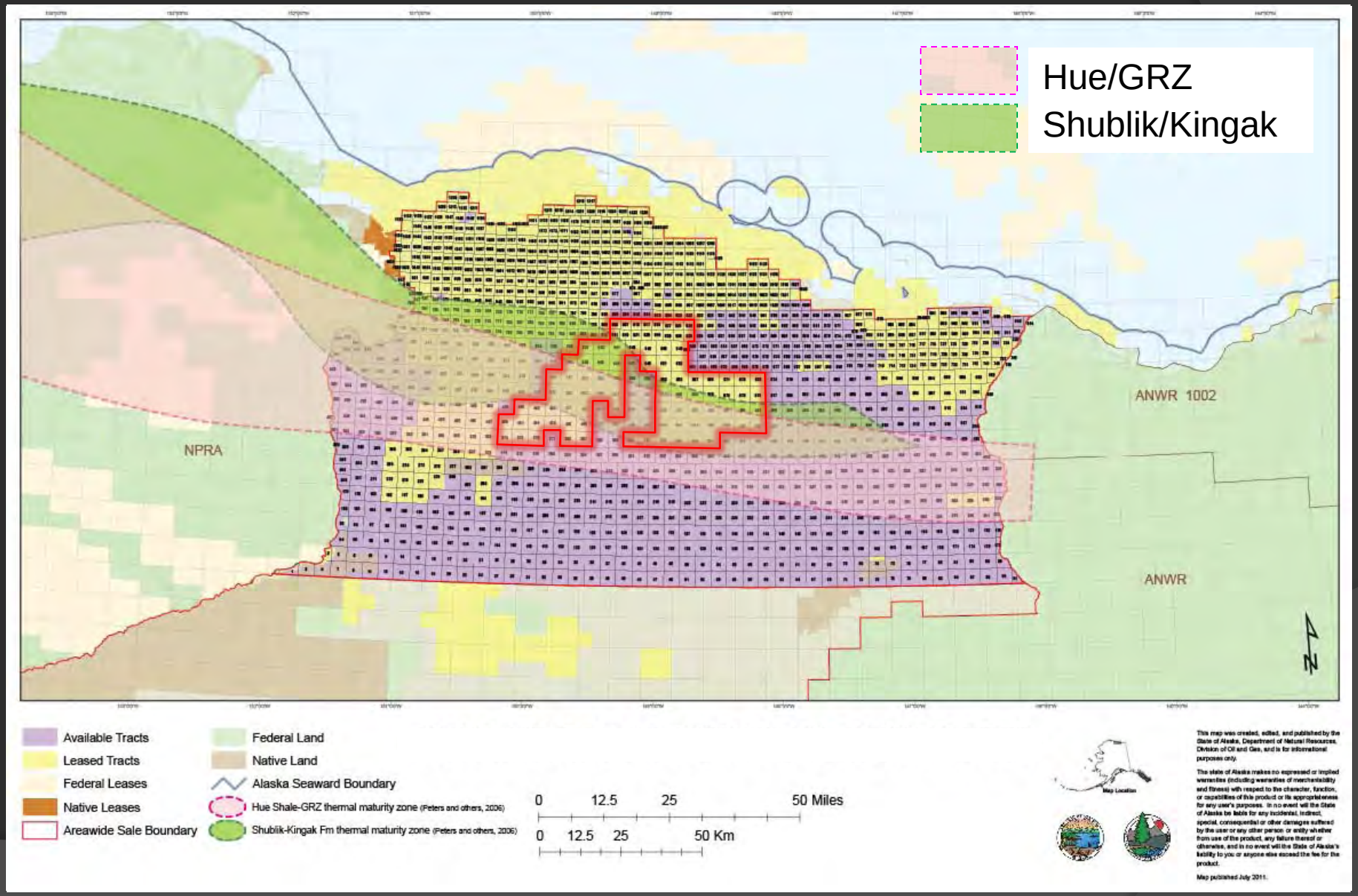
- North Slope Areawide
  - Encompasses 5.1 million acres onshore, including the core producing area north of the Umiat baseline between NPRA and ANWR
  - Barrow Arch crest and southern flank, northern Colville Basin
  - Conventional oil and gas prospects in structural, stratigraphic, and combination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

Leased *(July 2011)*

Available



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

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