

# Brookian Topset Stratigraphic Play: *Petroleum Systems Elements*

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Alaska Geological Society Meeting

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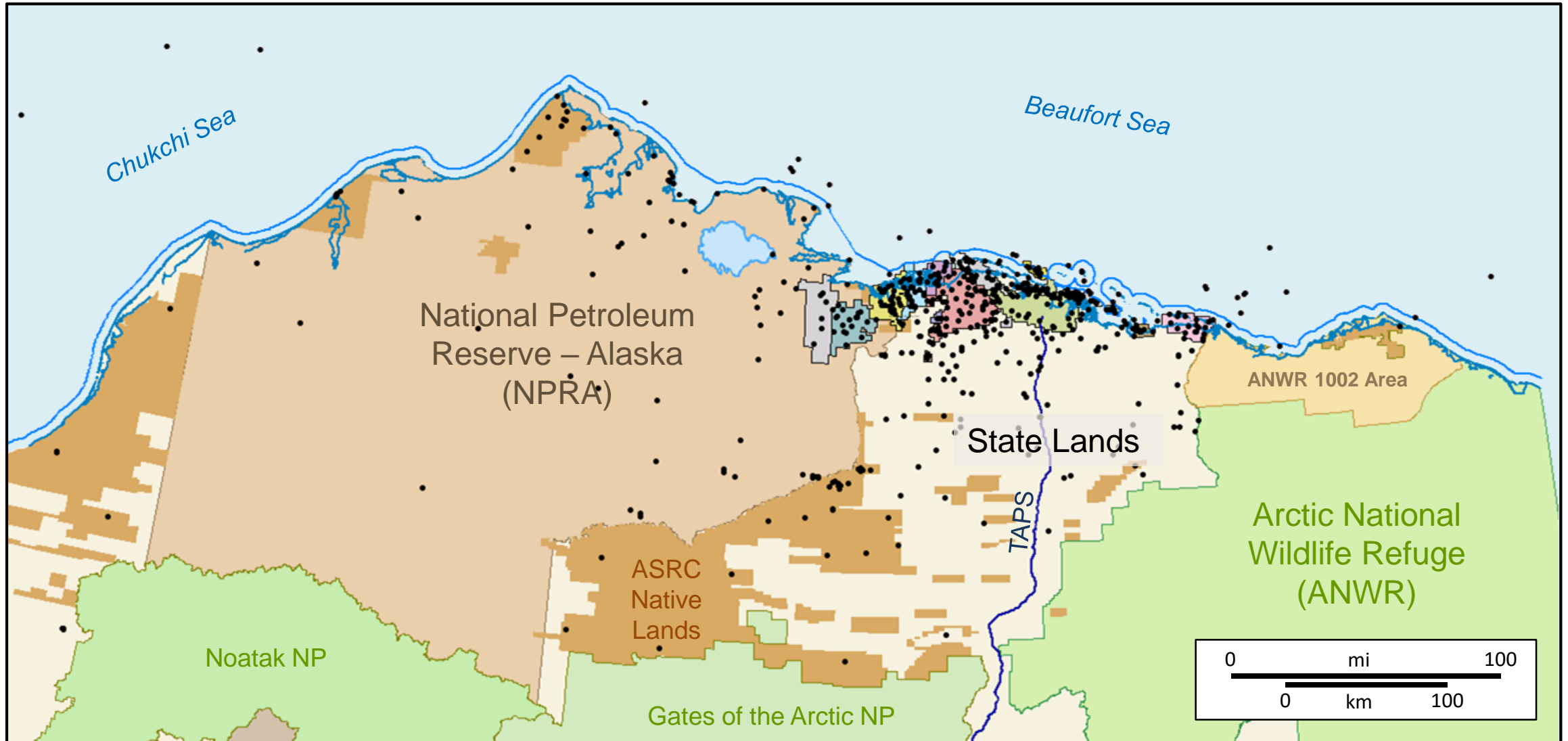
# TOPICS & THEMES

- North Slope introduction and recent activity
- Regional geology – Nanushuk & Torok Fm plays
- Compare & contrast recent major discoveries
- Barrow Arch region vs. other areas
- Implications for undiscovered oil

*Nanushuk Formation, Killik Bend, Colville River*

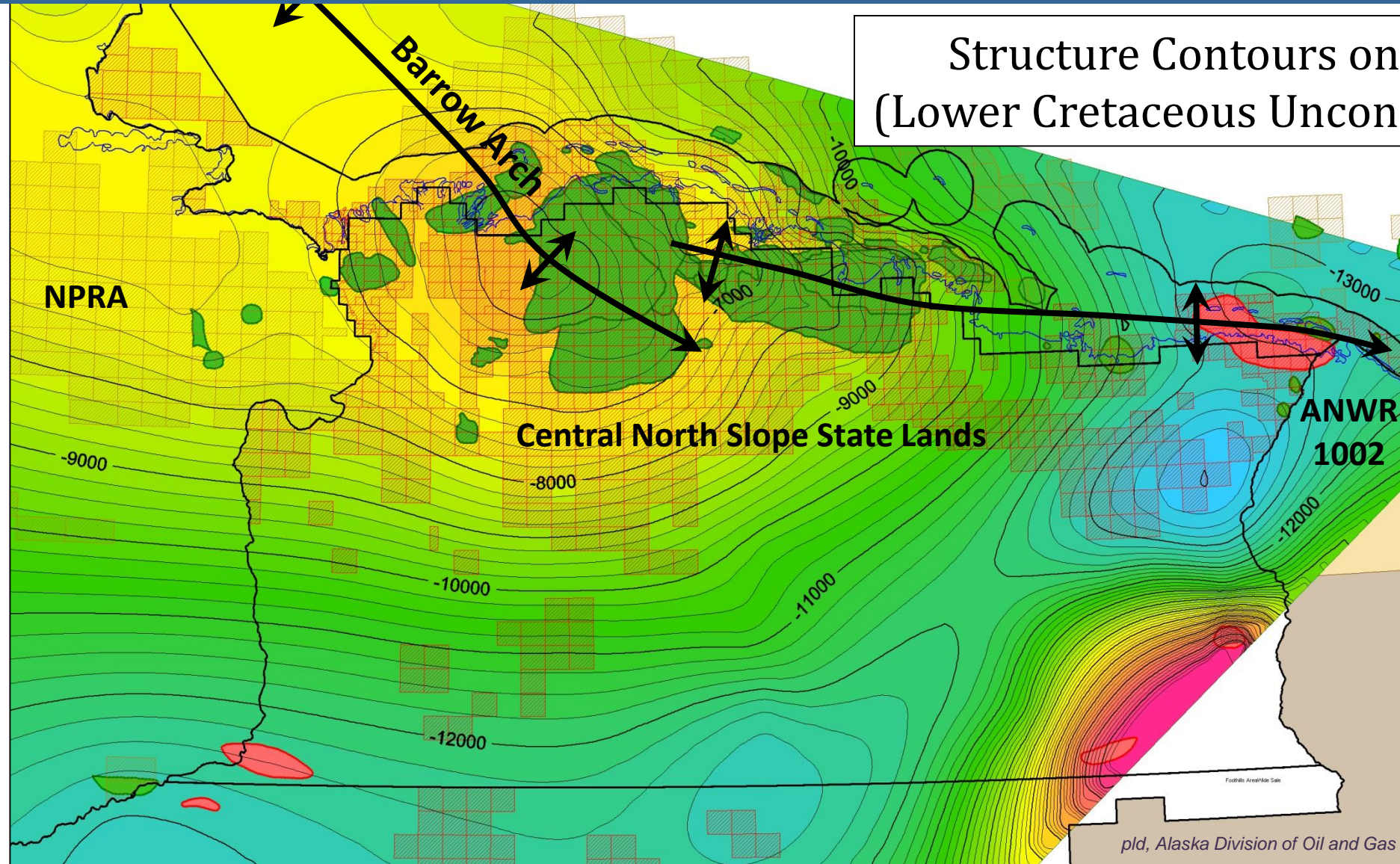
# NORTHERN ALASKA

## - UNDEREXPLORED PETROLEUM PROVINCE -





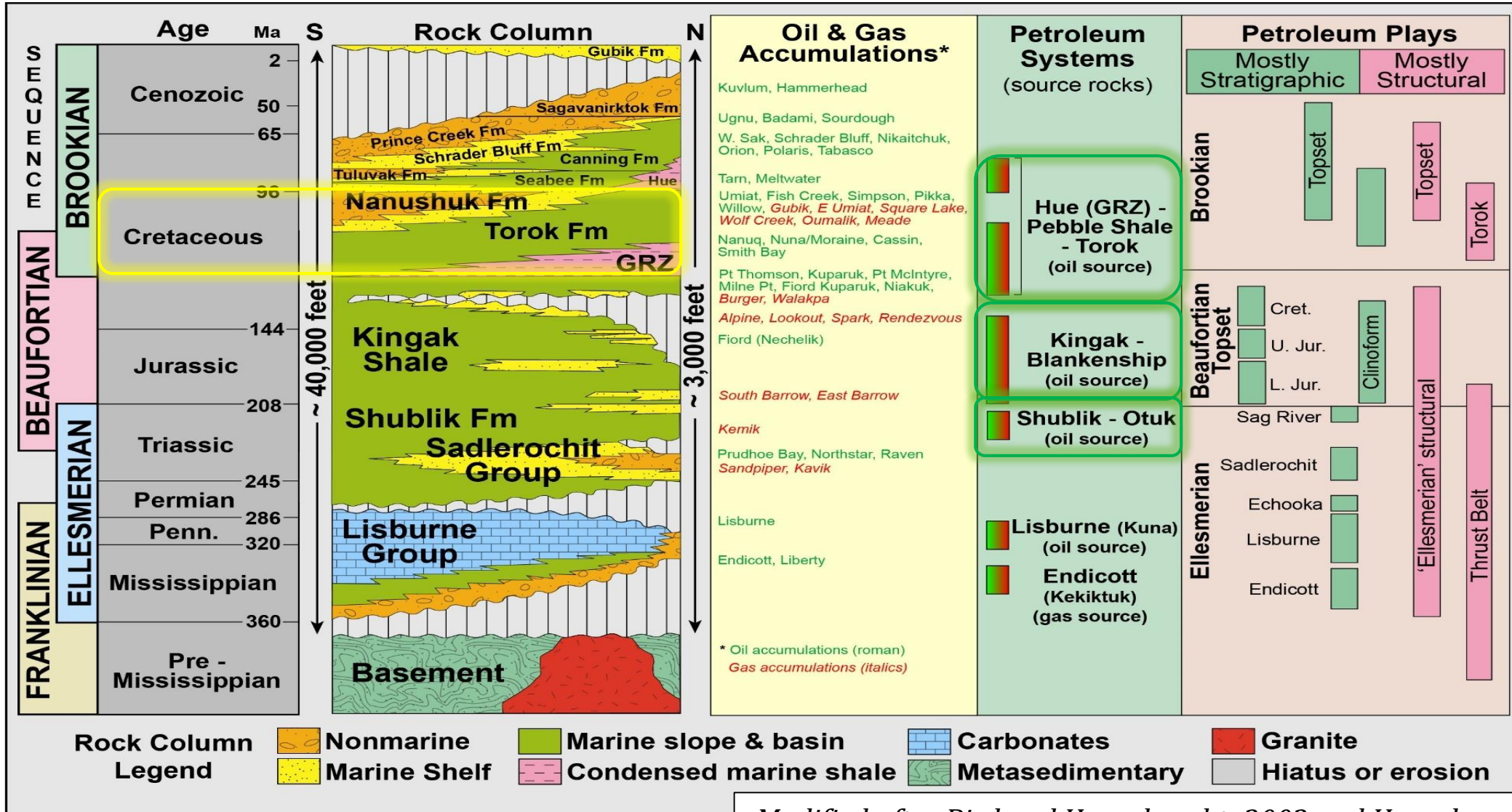
# NORTH SLOPE FIELDS & BARROW ARCH





# NORTH SLOPE PETROLEUM SYSTEMS

## - FOCUS ON LOWER BROOKIAN SEQUENCE -





# RECENT BROOKIAN DISCOVERIES

## - NANUSHUK AND TOROK FORMATIONS -

*Several exciting Nanushuk and Torok Formation discoveries are at different stages of maturity.*

*The 2018 winter exploration season saw 7 Nanushuk penetrations, 5 flow tests, and a 250-square-mile 3D survey in the Pikka-Narwhal-Horseshoe and Willow trends.*

Interior Department reviewing 2013 restrictions on future leasing in northern NPRA.

USGS assessment released in December 2017 sharply increased estimates of NPRA's undiscovered oil resource.

Unavailable to Leasing and no new non-subsistence infrastructure

Unavailable to Leasing

National Petroleum Reserve - Alaska (NPRA)

25 mi

Undrilled Prospects (ConocoPhillips)

Willow-West Willow (Nanushuk Fm topsets)

Cassin (Torok Fm turbidites)

Nuna/Moraine (Torok Fm turbidites)

Pikka-Horseshoe/Narwhal (Nanushuk Fm topsets)

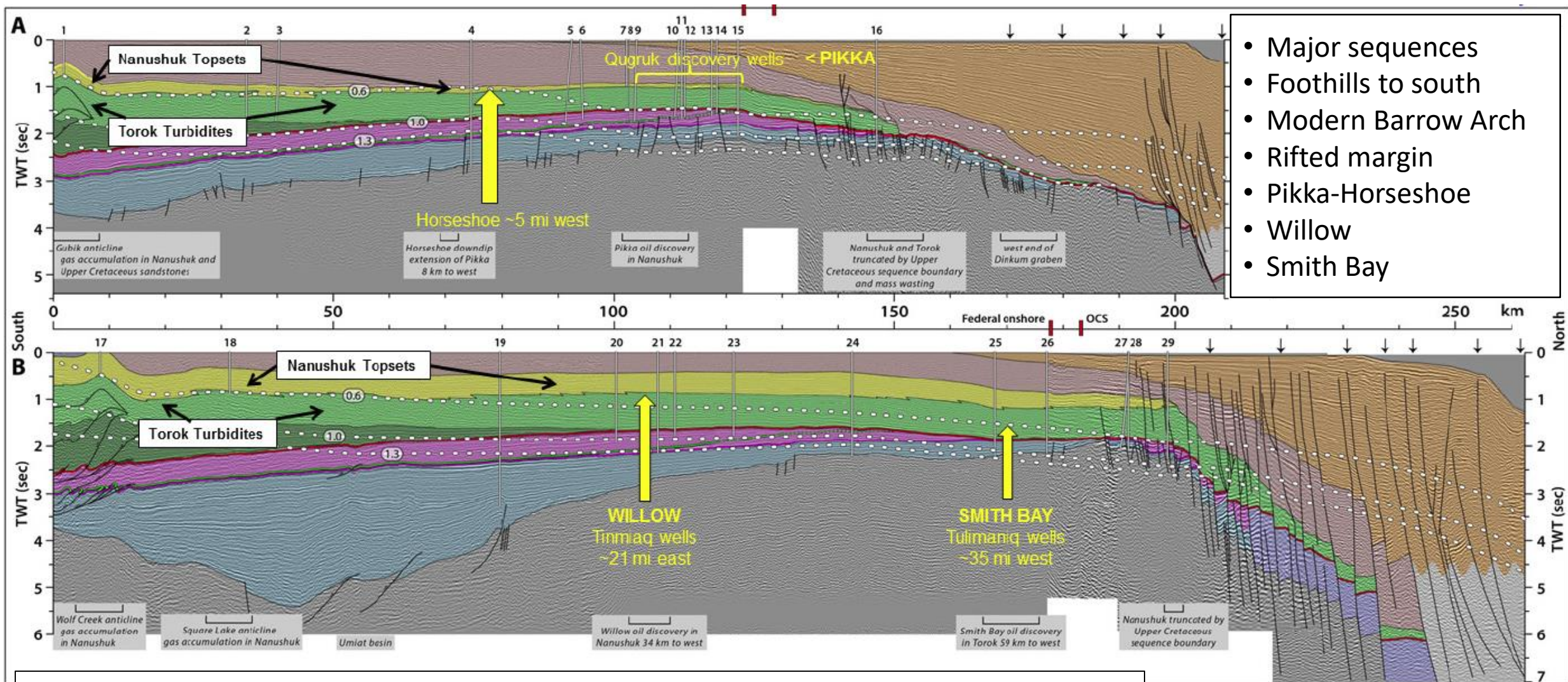
Horseshoe 1, 1A (2017)

2018 Bear 3D



# NORTH SLOPE TECTONIC SETTING

## - NANUSHUK AND TOROK DISCOVERIES -



Interpreted seismic profiles courtesy of David Houseknecht, USGS (in BOEM Fact Sheet 2017-12b)



# MAJOR RECENT BROOKIAN DISCOVERIES

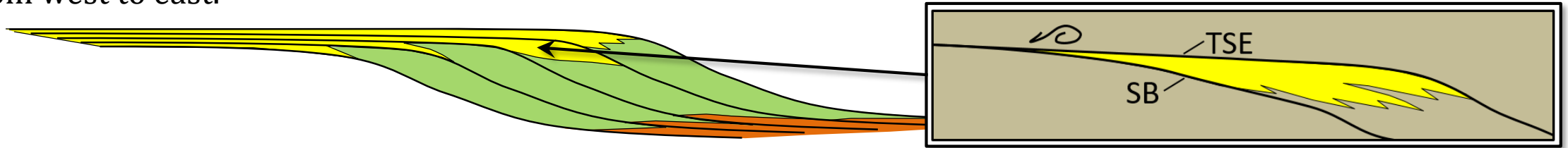
	Smith Bay	Willow	Pikka-Horseshoe/Narwhal
<b>Operator(s)</b>	Caelus	ConocoPhillips	Oil Search/ConocoPhillips
<b>Reservoir Formation</b>	Torok Fm	Nanushuk Fm	Nanushuk Fm
<b>Penetrations to date</b>	2	7	12
<b>Location</b>	State Waters <b>Offshore</b> of NPRA	Federal Onshore Northeast NPRA	Onshore Colville Delta
<b>Road/Pipeline Tie-in</b>	~ 125 miles	~ 28 miles	~ 20 miles
<b>Trap type</b>	<b>Turbidite</b> Stratigraphic	Topset Stratigraphic	Topset Stratigraphic
<b>Net Pay</b>	183-223 ft	42-72 ft	< 225 ft
<b>Oil Gravity</b>	40-45 degree API (calc)	41-44 degree API	30 degree API
<b>Test Rate</b>	<b>No Flow Tests</b>	< 3,200 bopd vertical	~ 2,100 bopd vertical; 4,600 bopd horizontal
<b>Contingent Recoverable Resource</b>	1.8-2.4 BBO (est)	400-750 MMBO	1.15-1.4 BBO*
<b>Expected Production (Operator Releases)</b>	< 200,000 bopd	100,000 bopd	< 120,000 bopd

\* Oil Search estimates assume 2019 delineation drilling successful; moves some 3C resource to 2C (P50) resource category.



# OVERVIEW OF BROOKIAN SEQUENCE AND PLAYS

- The Brookian sequence represents a wide range of clastic rocks shed from the Chukotka and ancestral Brooks Range orogens into the Colville foreland basin during Cretaceous and Tertiary time.
- Multiple formations and clinoformal successions make up the Brookian sequence, which filled the basin from west to east.

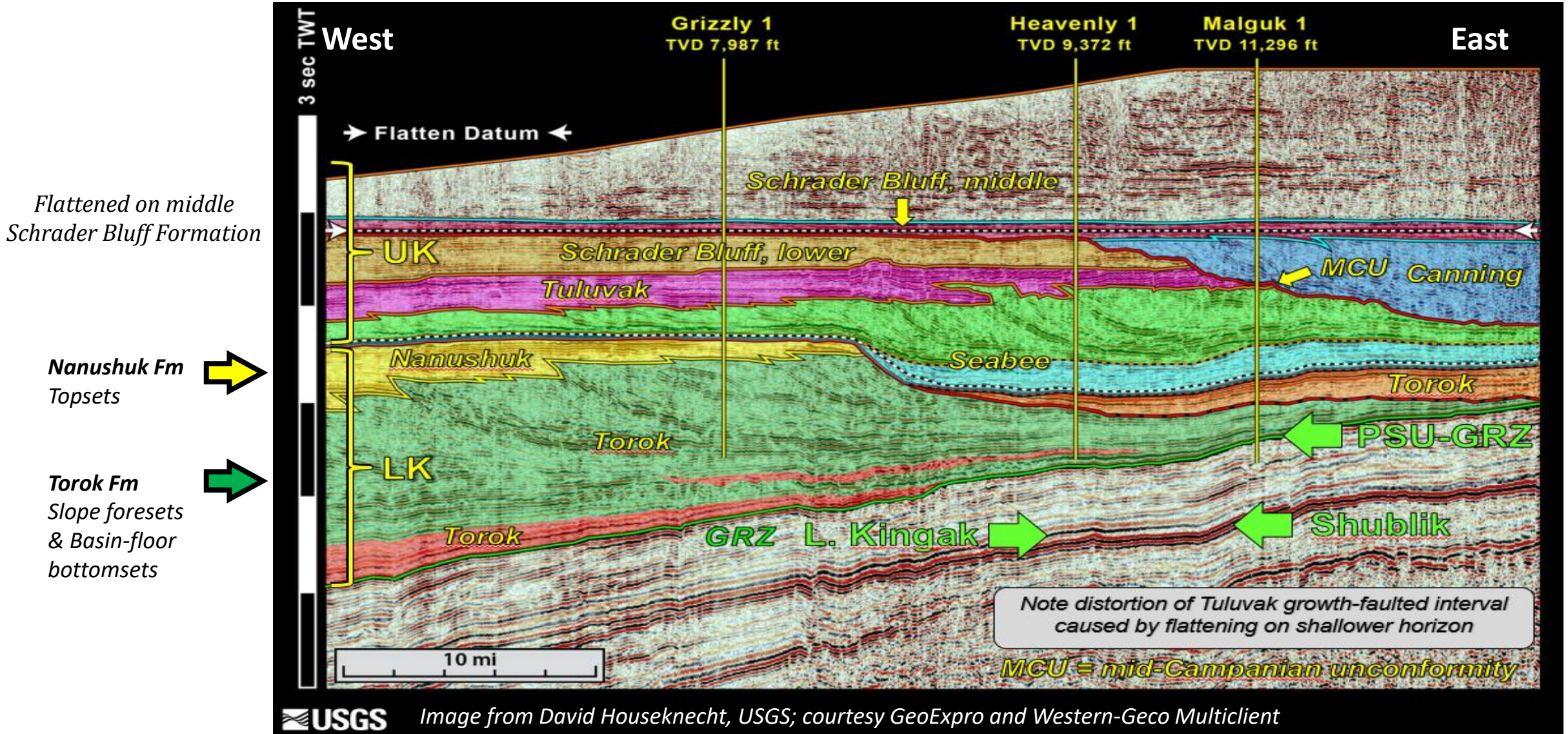


- Readily apparent in seismic, Brookian clinoforms consist of
  - **Topsets:** sand-prone coastal plain and shallow marine shelf;
  - **Foresets:** muddy slope and sandy turbidite channels and slope apron fans;
  - **Bottomsets:** sandy basin-floor turbidites, organic-rich condensed shales.
- In the central to western North Slope, the topsets are the Nanushuk Formation, whereas the time-equivalent foresets and bottomsets represent the Torok Formation.
- The newly proven play is stratigraphically trapped sandstones deposited on muddy outer shelf strata during falling stage or lowstand stage, and sealed by overlying mudstone deposited with next transgression.



# BROOKIAN SEQUENCE CLINOFORMS

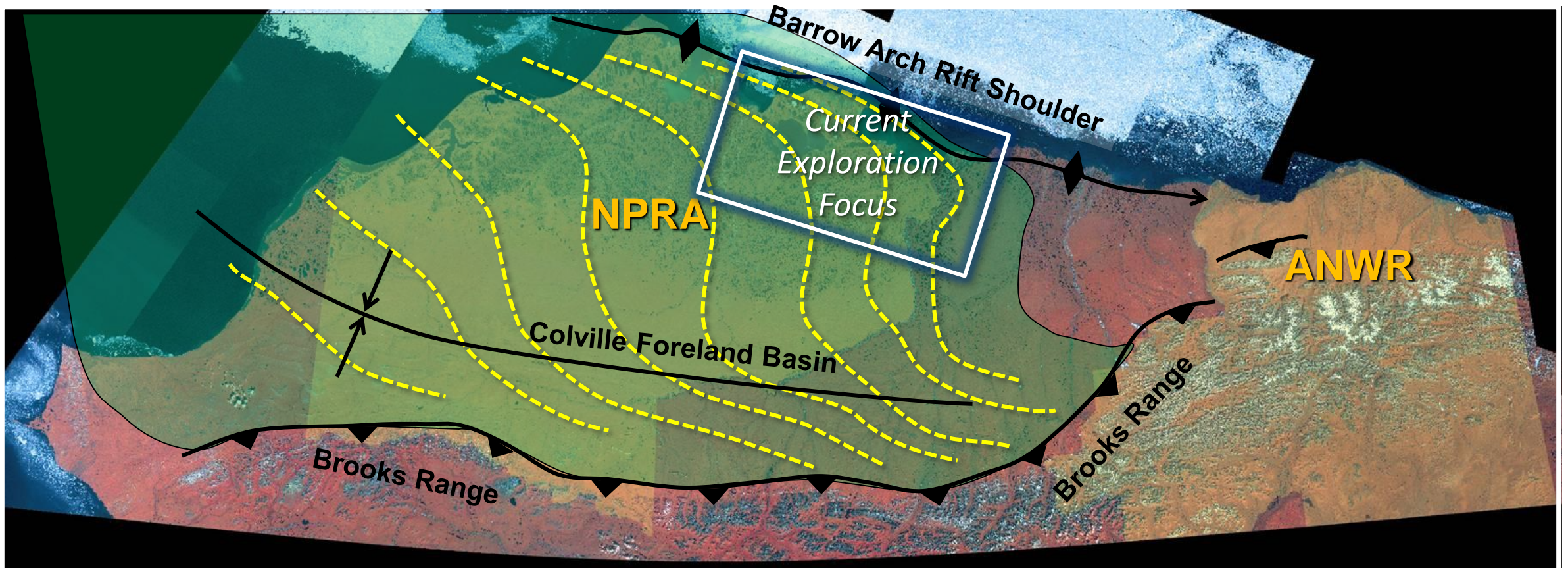
## - CENTRAL NORTH SLOPE STATE LANDS -





# NANUSHUK-TOROK DEPOSITIONAL SYSTEM

## - REGIONAL PLAY EXTENTS -

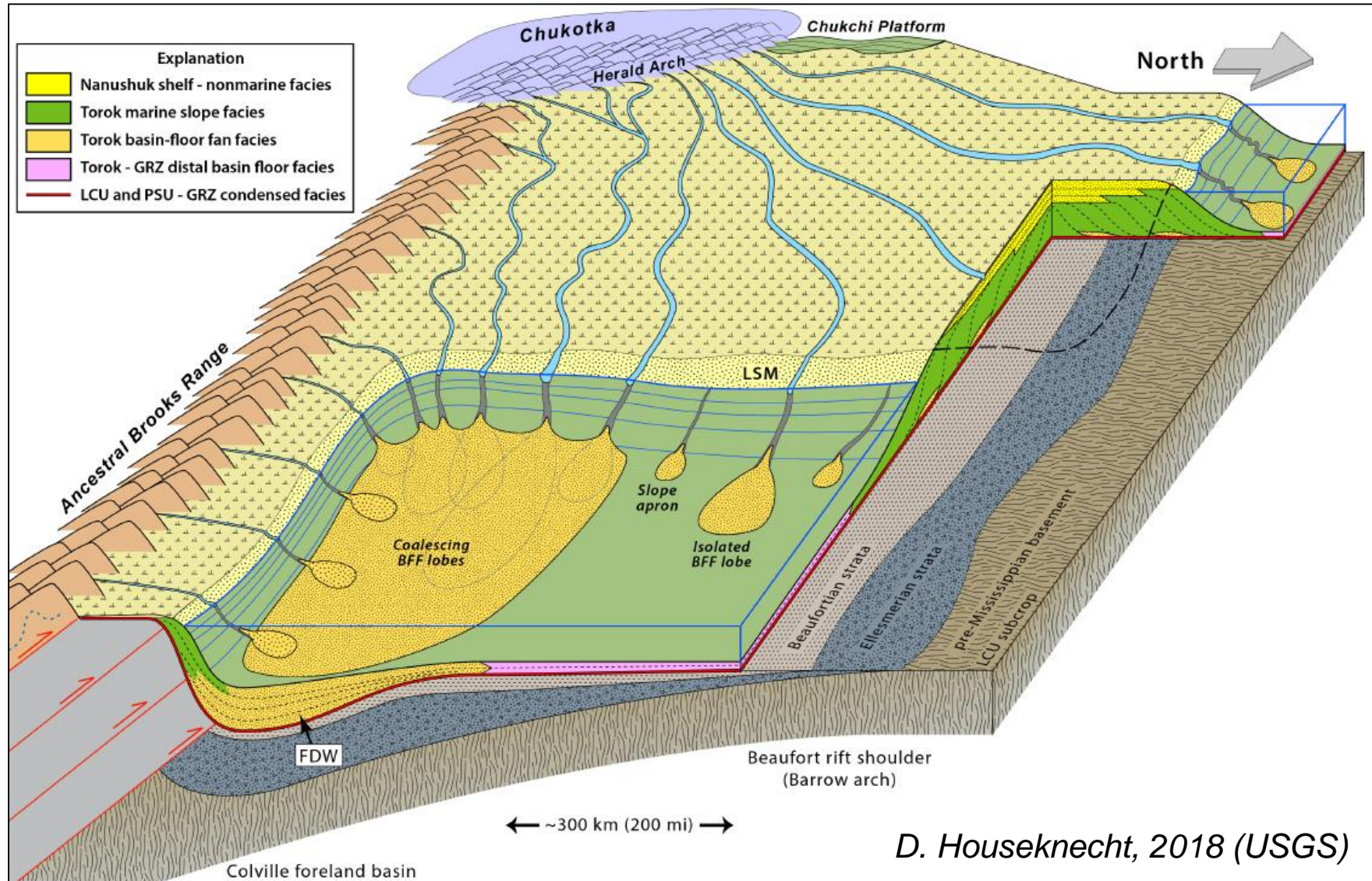


- Overall progradation of Nanushuk-Torok clinothem across foreland basin illustrated schematically as series of advancing shelf margins (dashed yellow lines).
- Numerous higher-order sea-level fluctuations repeatedly set up potential for enhanced reservoir and strat traps.
- Nanushuk and Torok Formation plays exist over large areas of the central and western North Slope.



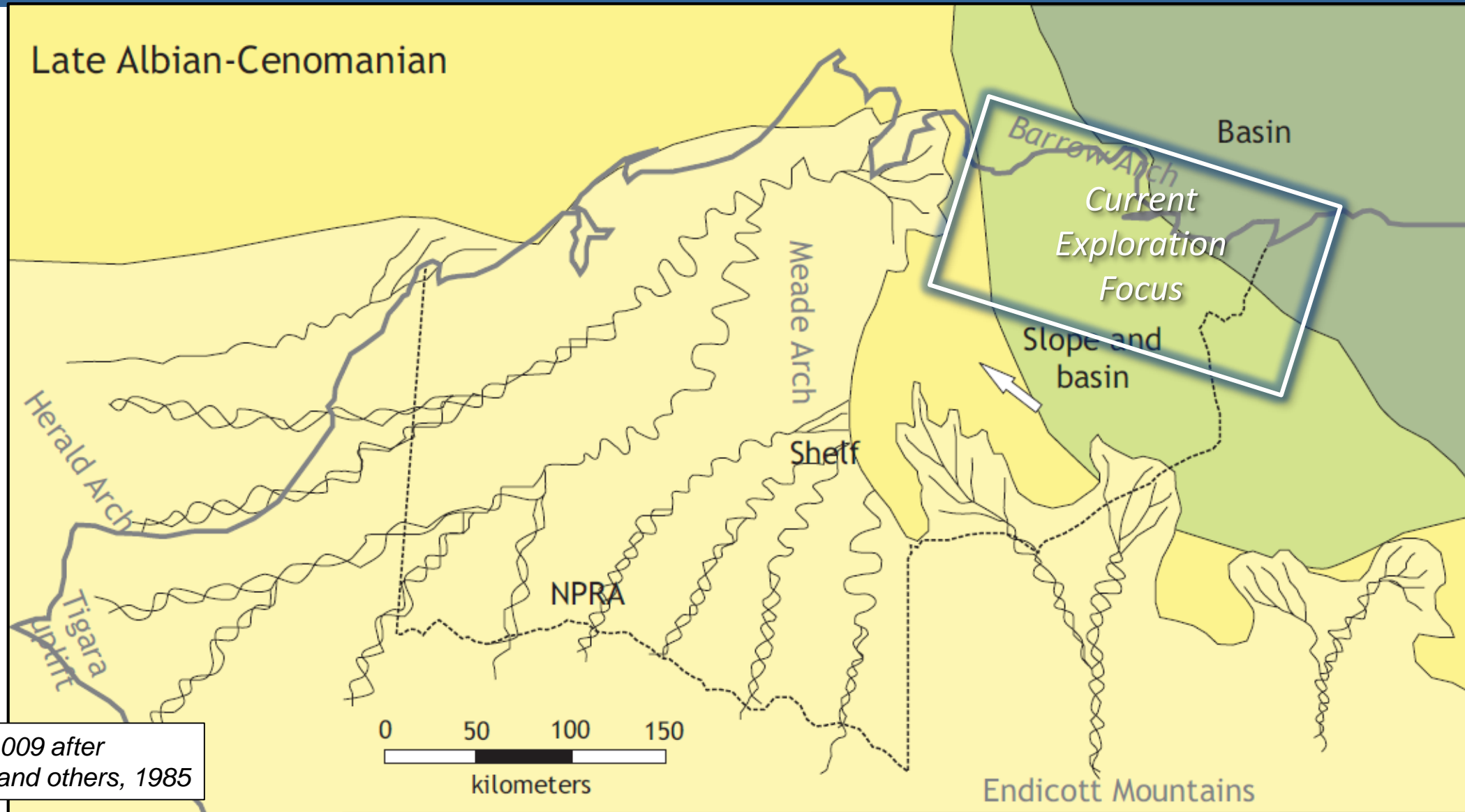
# NANUSHUK-TOROK DEPOSITIONAL SYSTEM

## - AXIAL & TRANSVERSE FORELAND BASIN SEDIMENTATION -





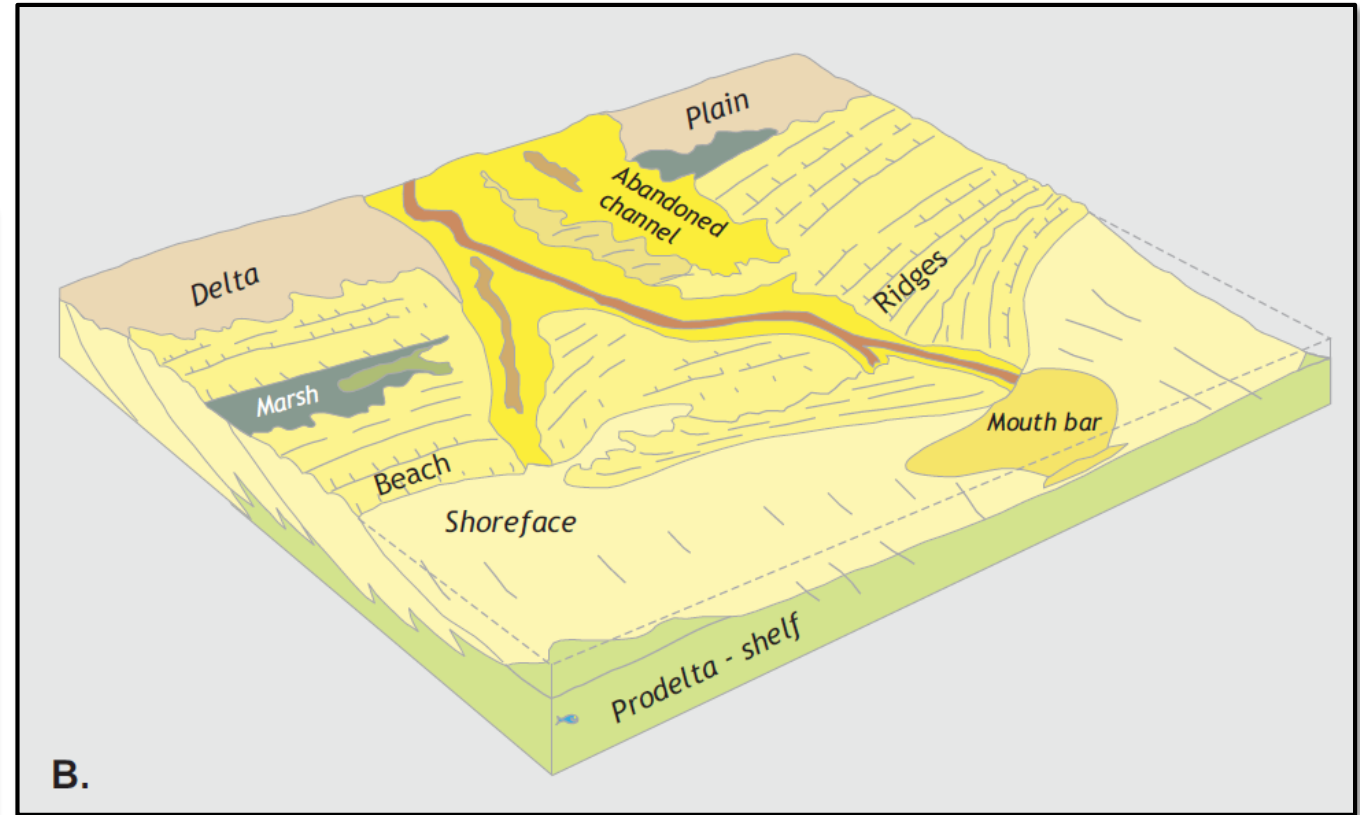
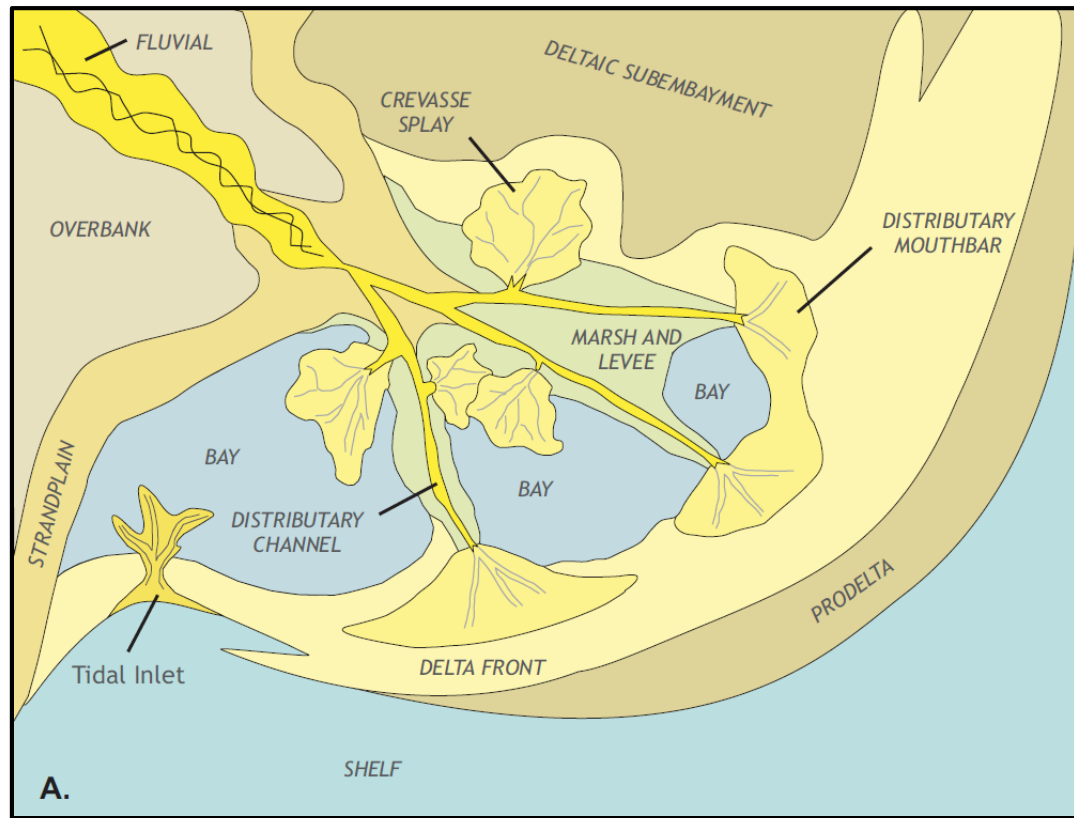
# NANUSHUK-TOROK PALEOGEOGRAPHY



LePain, 2009 after  
Huffman and others, 1985

# NANUSHUK DELTAIC ASSOCIATIONS

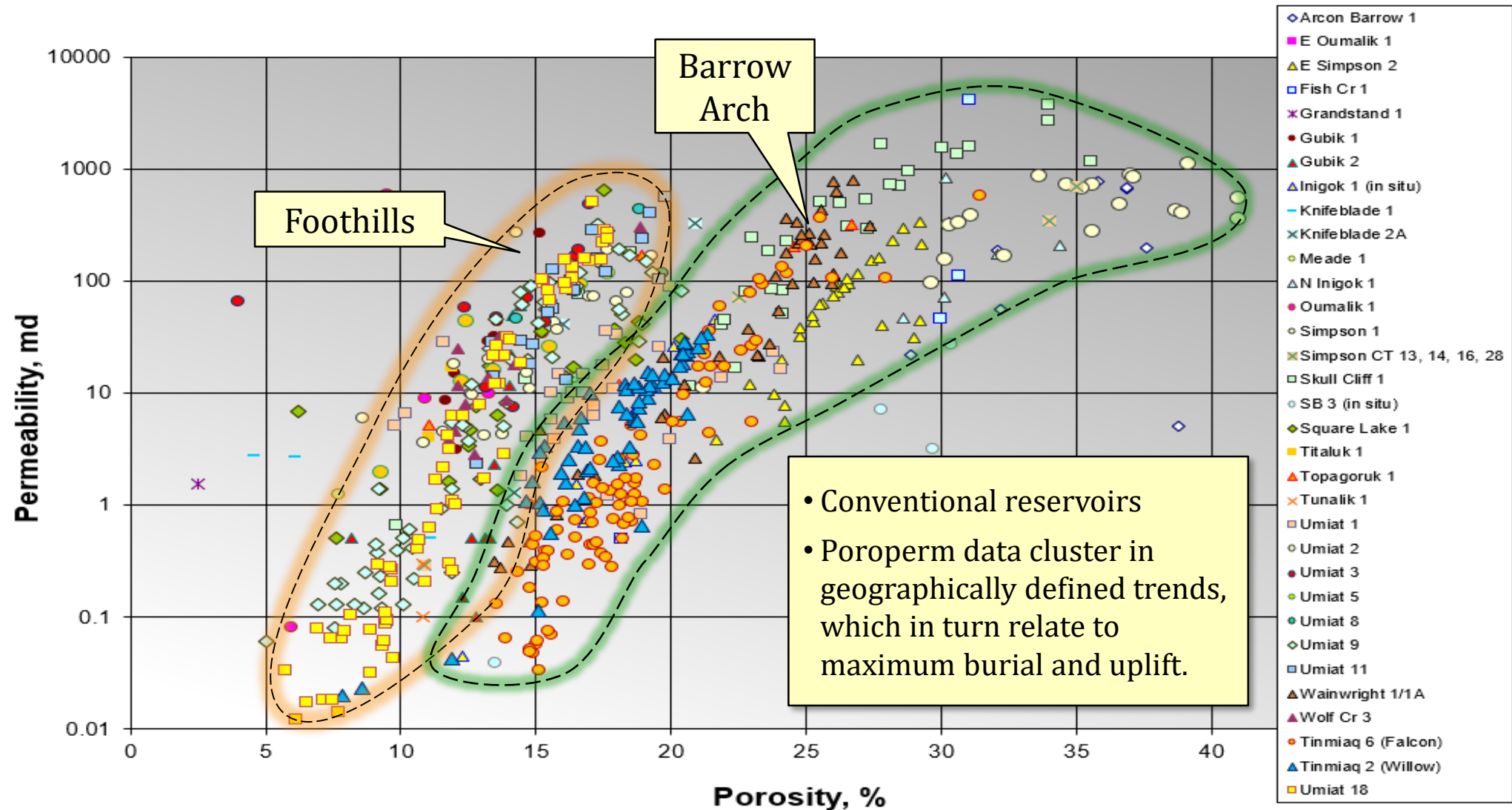
## Wave-modified lobate delta



## Wave-dominated cusped delta



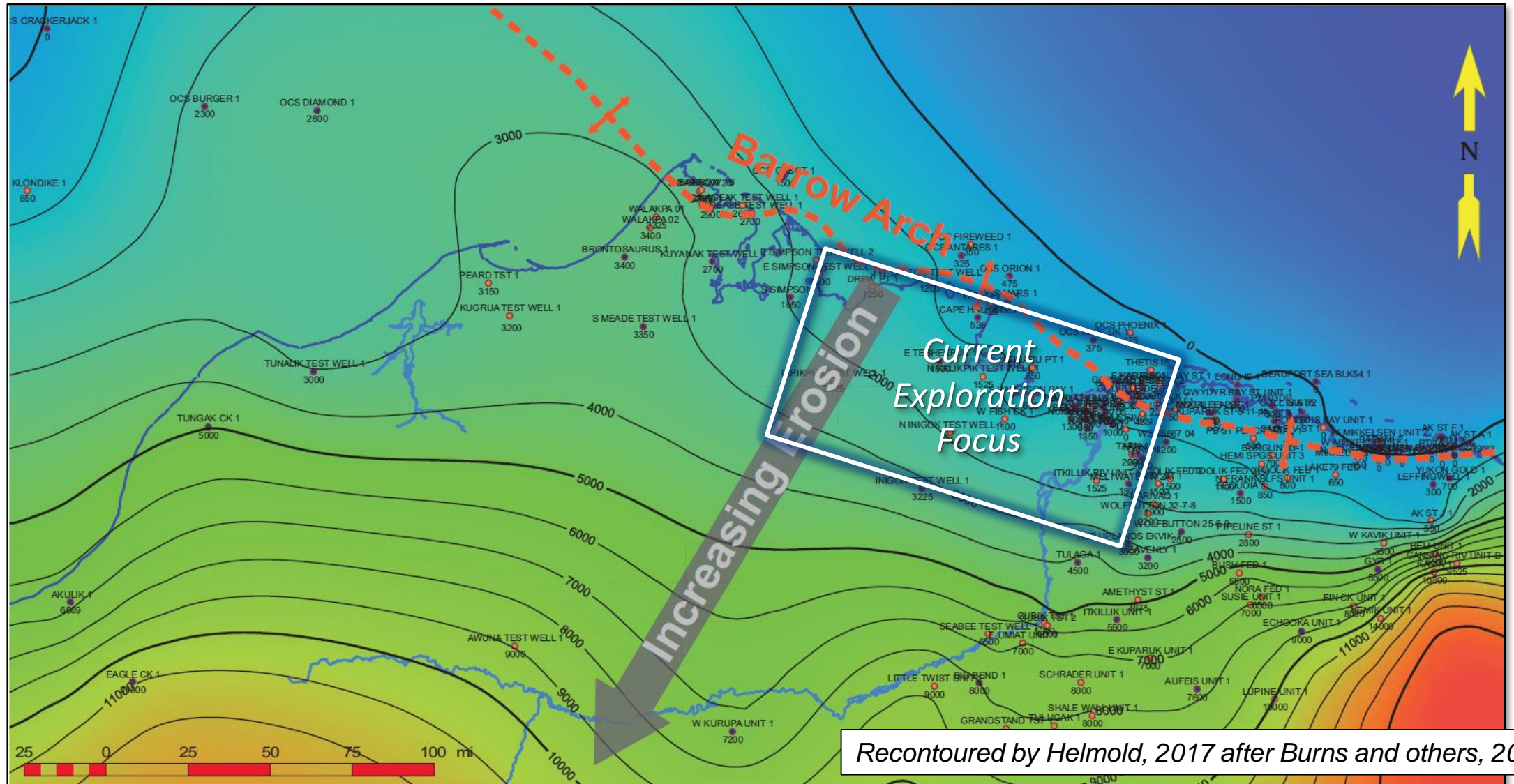
# NANUSHUK FM RESERVOIR QUALITY





# CENOZOIC UPLIFT AND EROSION

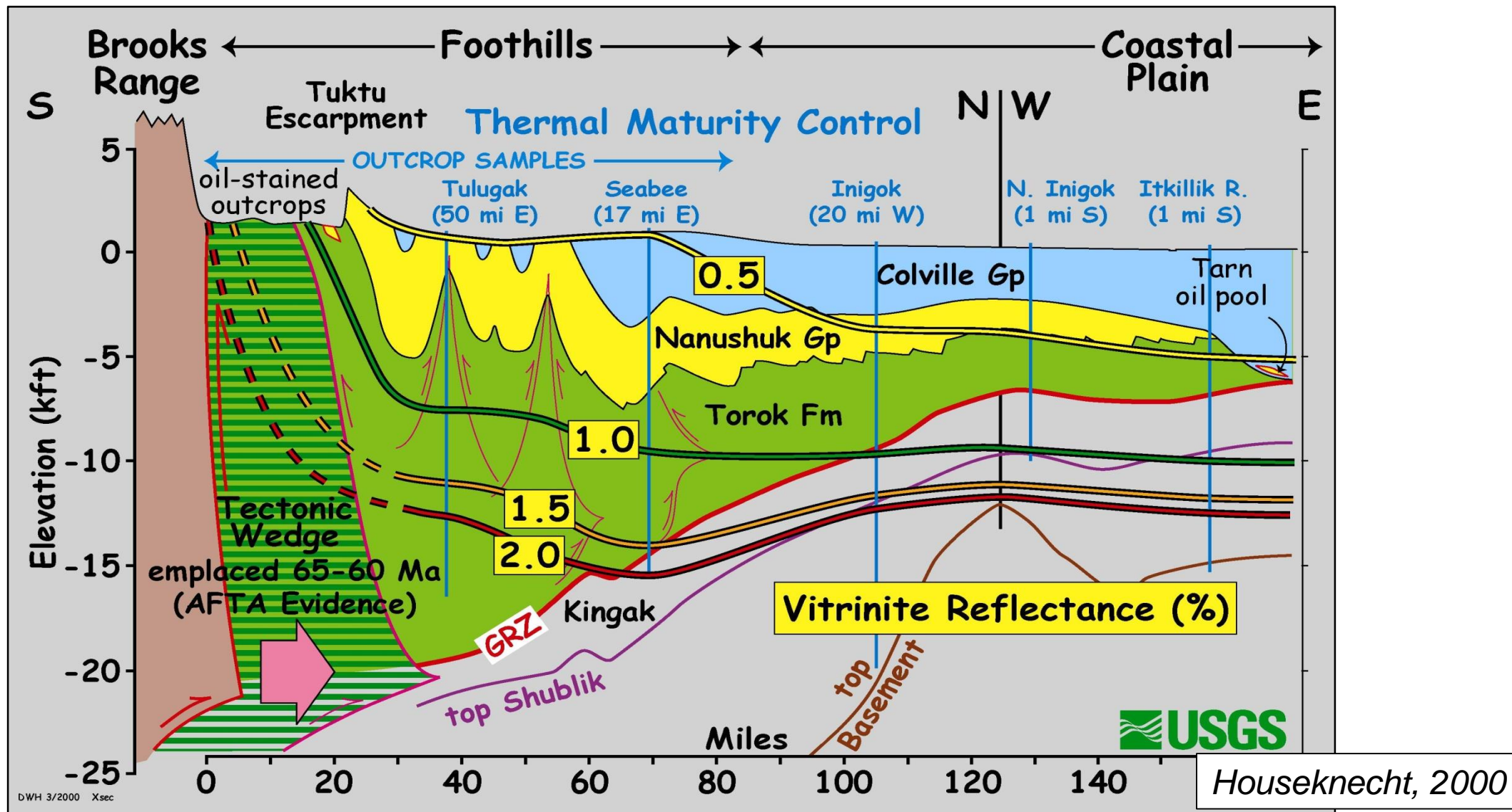
## - COMPACTION EFFECTS ON RESERVOIR QUALITY -





# COLVILLE BASIN THERMAL MATURITY

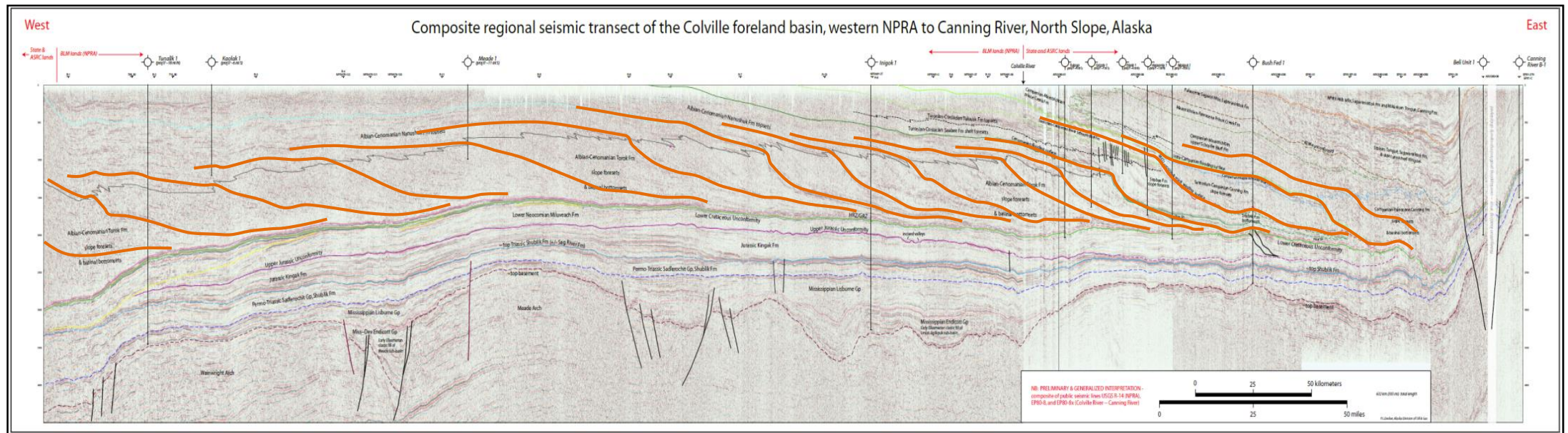
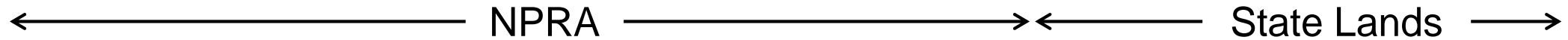
- ELEVATED MATURITY IN FOOTHILLS/FOREDEEP WEDGE -





# WEST-EAST REGIONAL SEISMIC TRANSECT

- WESTERN NPRA-COLVILLE RIVER-CANNING RIVER/ANWR -

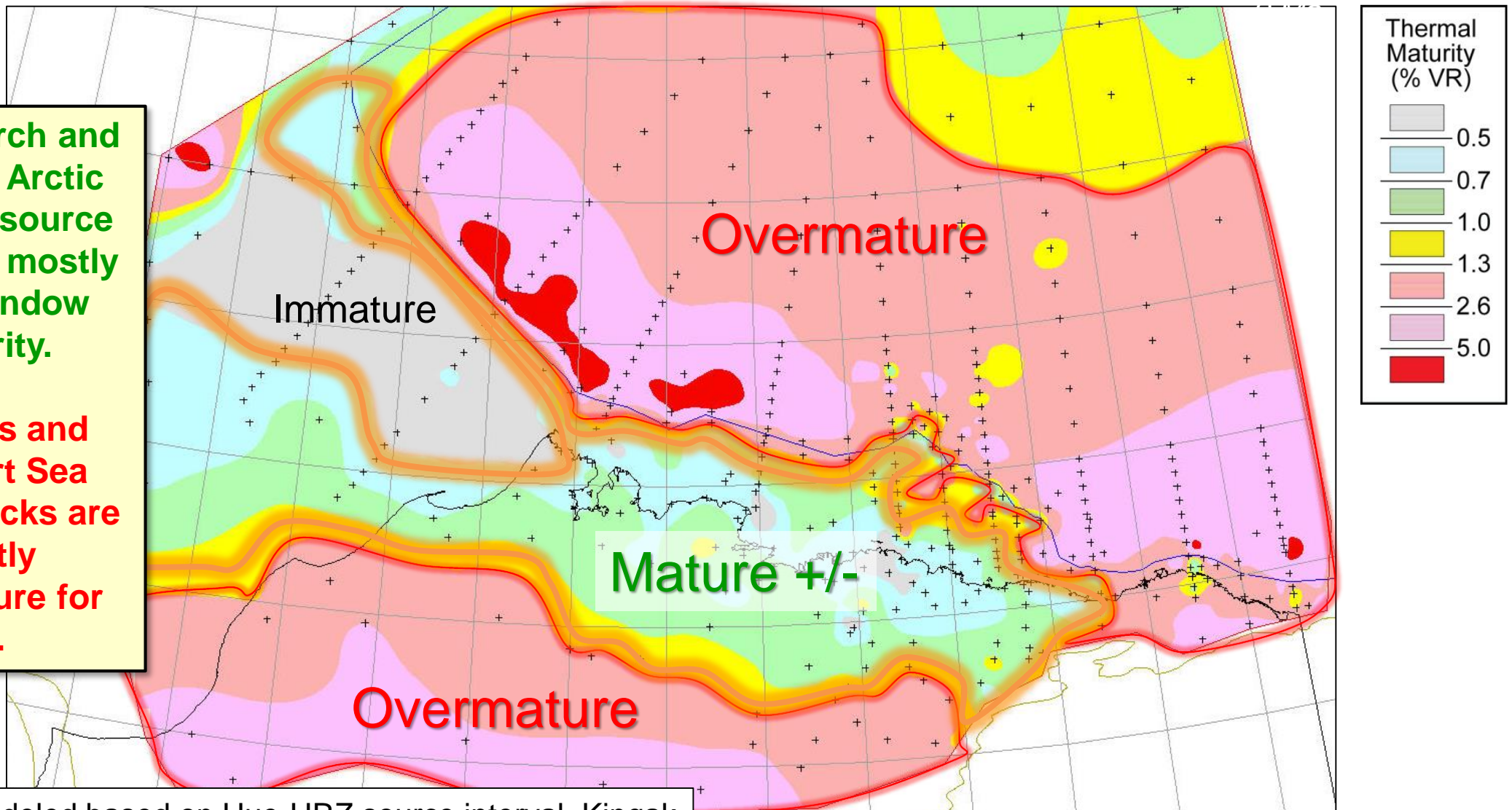


East-northeast progradation of Brookian clinoforms drove source rock burial and maturation, ~110 – 50 Ma

# THERMAL MATURATION OF SOURCE ROCKS\*

**Barrow Arch and adjacent Arctic Platform source rocks are mostly at oil window maturity.**

**Foothills and Beaufort Sea source rocks are mostly overmature for oil.**



\* Modeled based on Hue-HRZ source interval. Kingak and Shublik Fm source rocks are more mature.

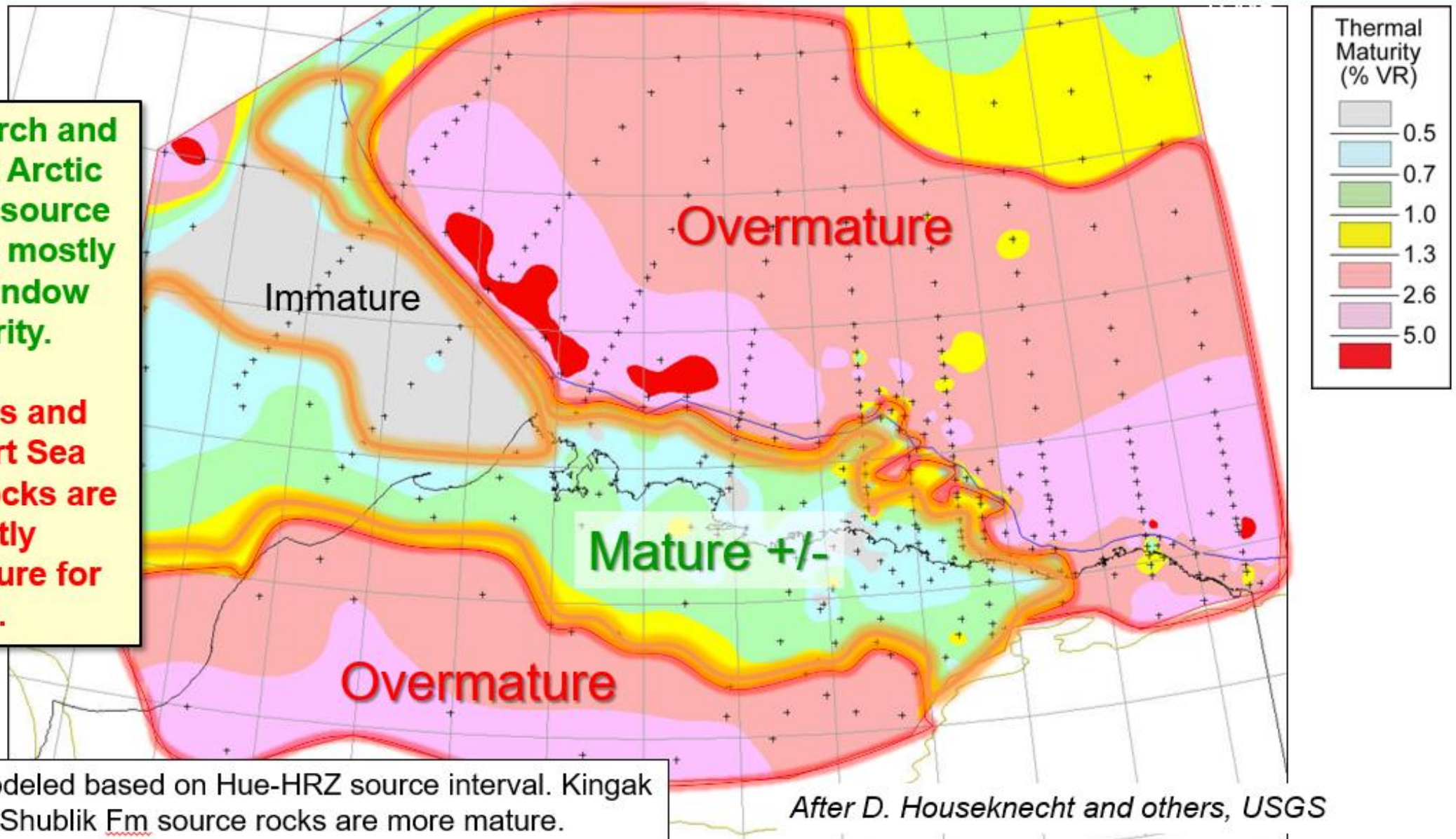
*After D. Houseknecht and others, USGS*



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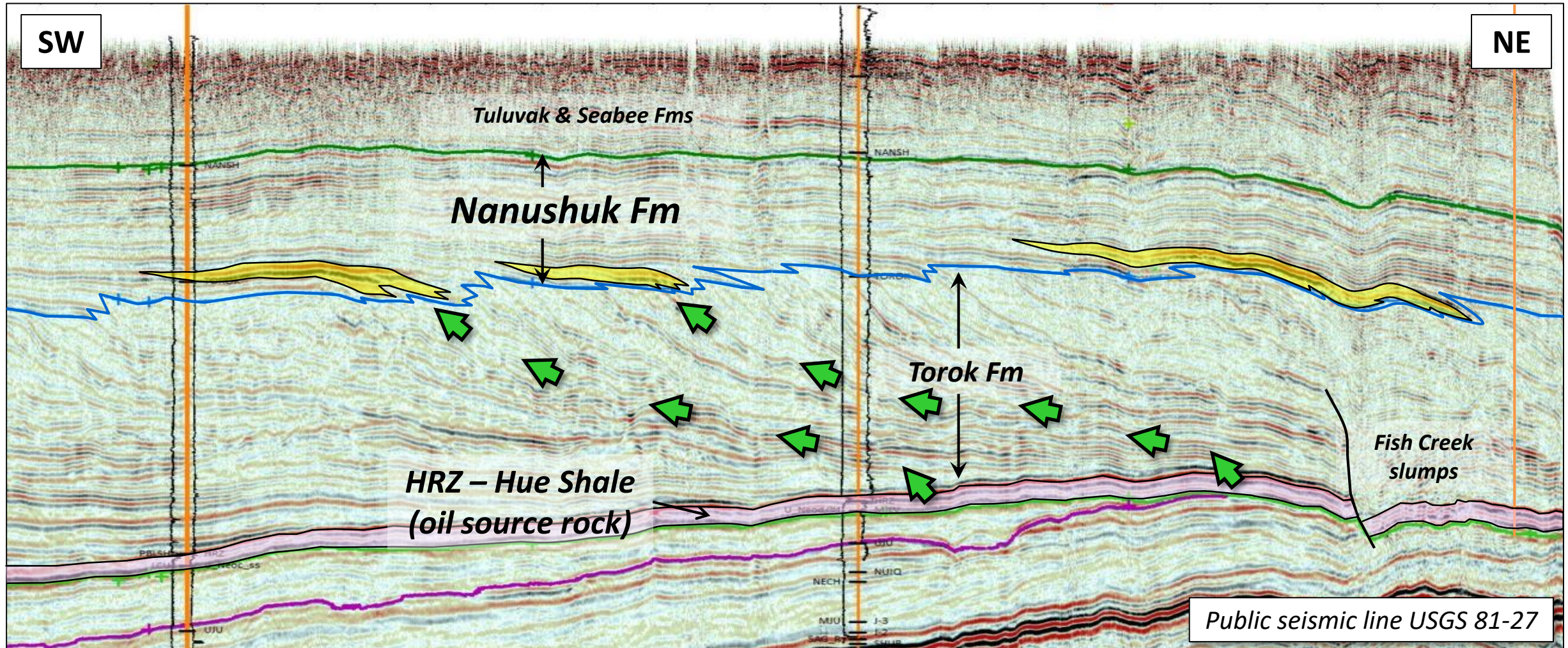
# HRZ-NANUSHUK OIL MIGRATION

## - NORTHEAST NPRA -

Inigok 1

North Inigok 1

North Kalikpik 1



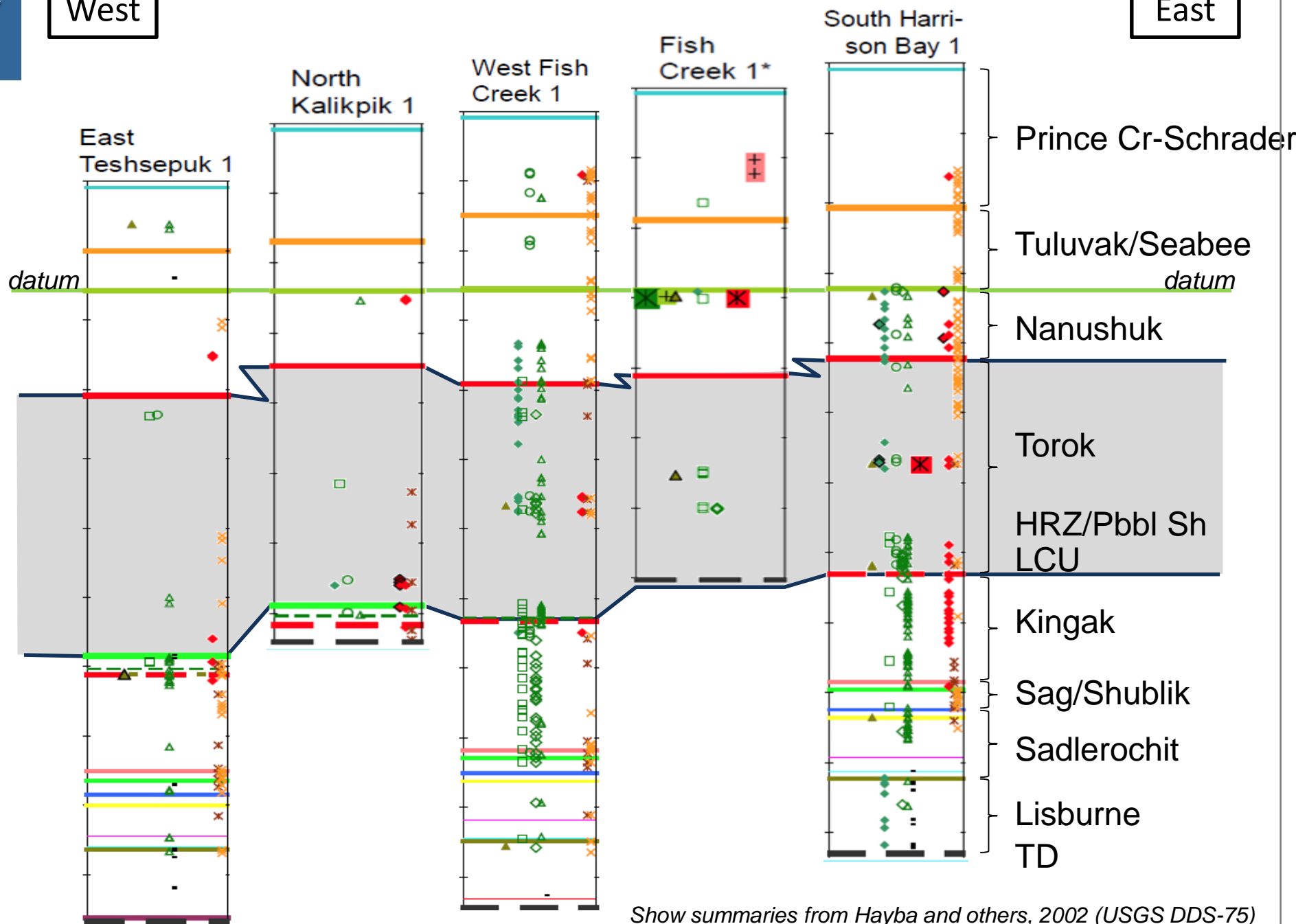


# WEST-EAST SHOW SUMMARY CROSS SECTION, NE NPRA

West

East

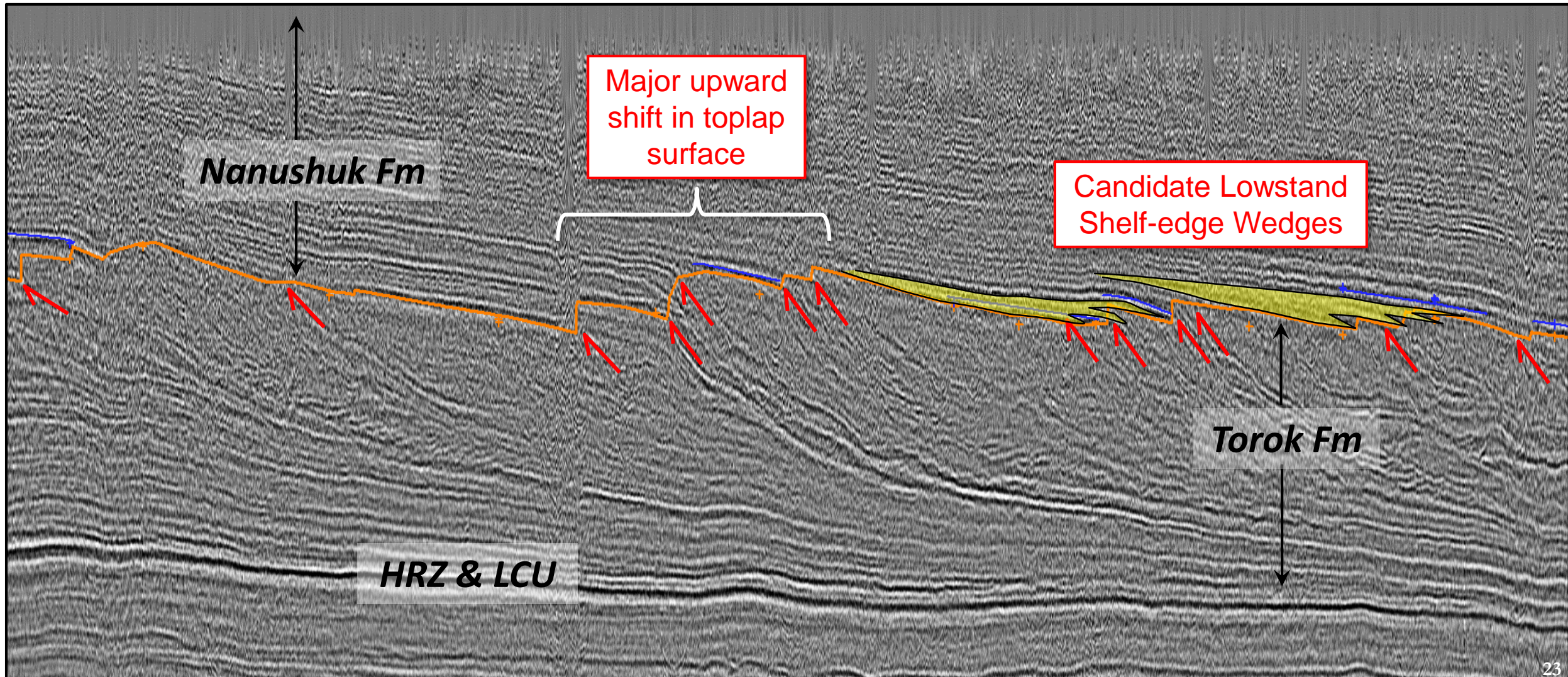
Explanation	
✱	Oil recovered in drill stem test
✱	Trace oil in drill stem test
+	Oil "bleeding" from core
▲	Stain—Good
▲	Stain—Fair
◆	Oil show
◆	Oil show—Slight
□	Visible oil cut
○	Fluorescence—Bright, Cut fluorescence—Strong
◇	Fluorescence—Medium, Cut fluorescence—Fair
△	Fluorescence—Dull, Cut fluorescence—Weak
•	Dead oil (bitumen, solid hydrocarbon)
✱	Gas recovered in drill stem test
✱	Trace gas in drill stem test
+	Gas "bleeding" from core
◆	Gas show
◆	Gas show—Slight
✱	Ethane (C <sub>2</sub> ) concentration >2,000 ppm
✱	Methane (C <sub>1</sub> ) concentration >20,000 ppm





# BASAL NANUSHUK TOPLAP SURFACE

## - PUBLIC 2D SEISMIC LINE NPRA REGIONAL R-15 -





## - TIME STRUCTURE, NPRA AND ADJACENT STATE LANDS PUBLIC 2D SEISMIC -



# BASAL NANUSHUK SHELF-MARGIN ANOMALIES

## - 3D SEISMIC, NORTHERN NPRA -

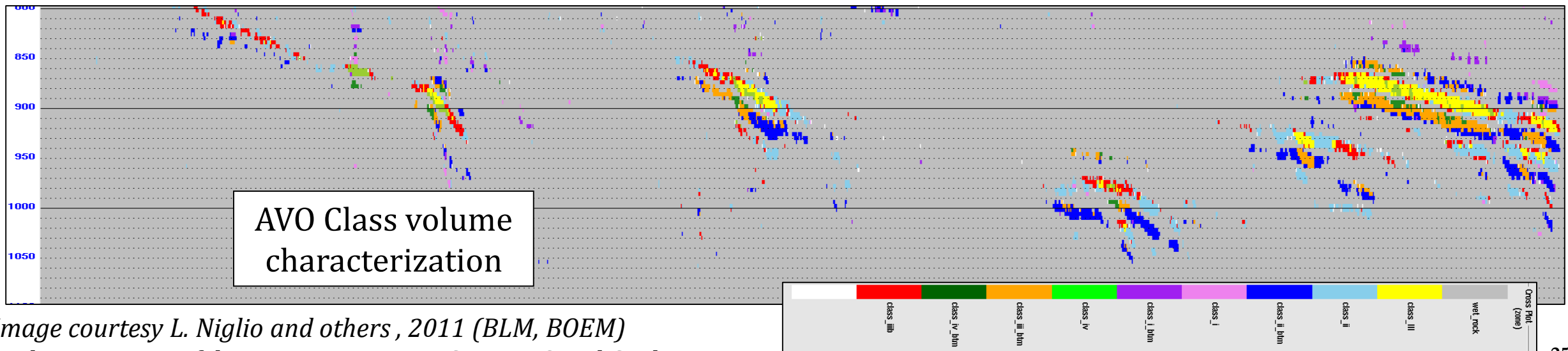
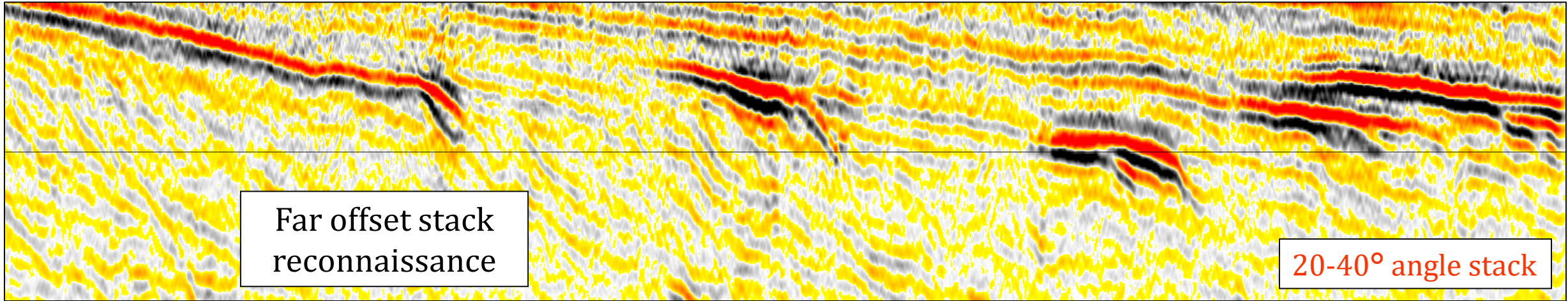
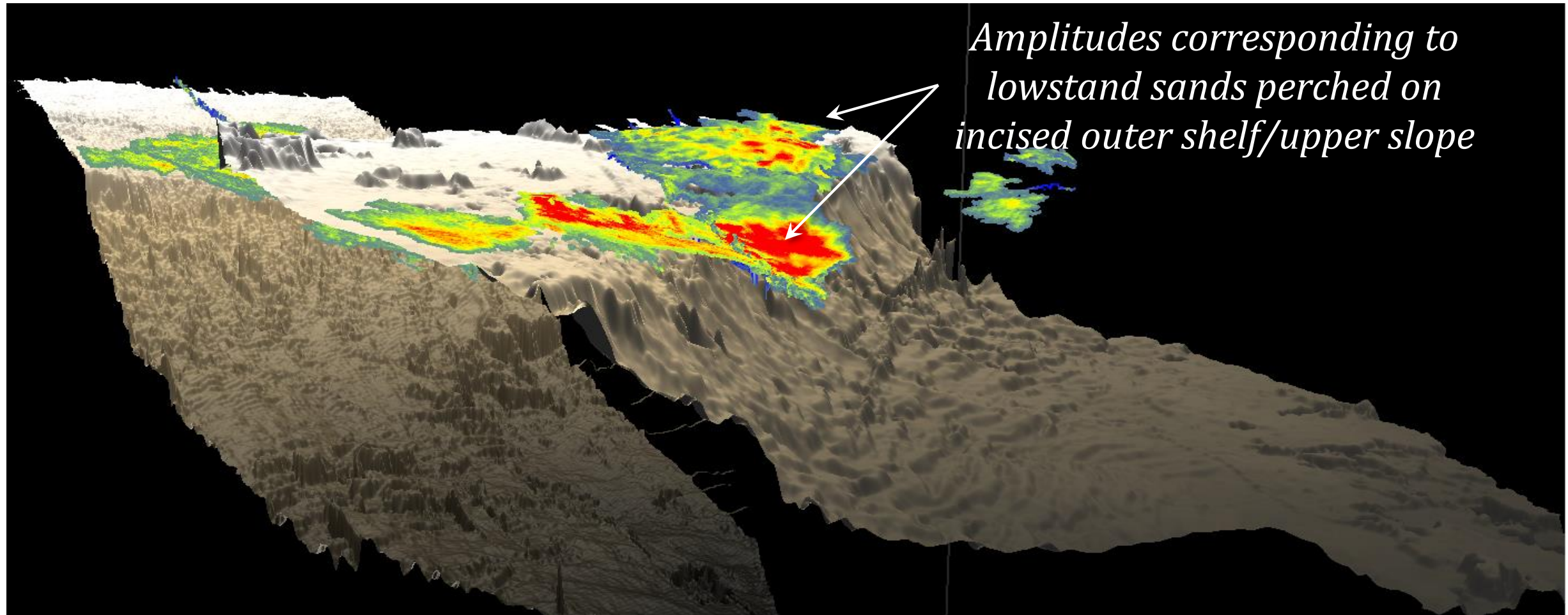


Image courtesy L. Niglio and others, 2011 (BLM, BOEM)  
with permission of data owners WesternGeco, LLC and Geokinetics



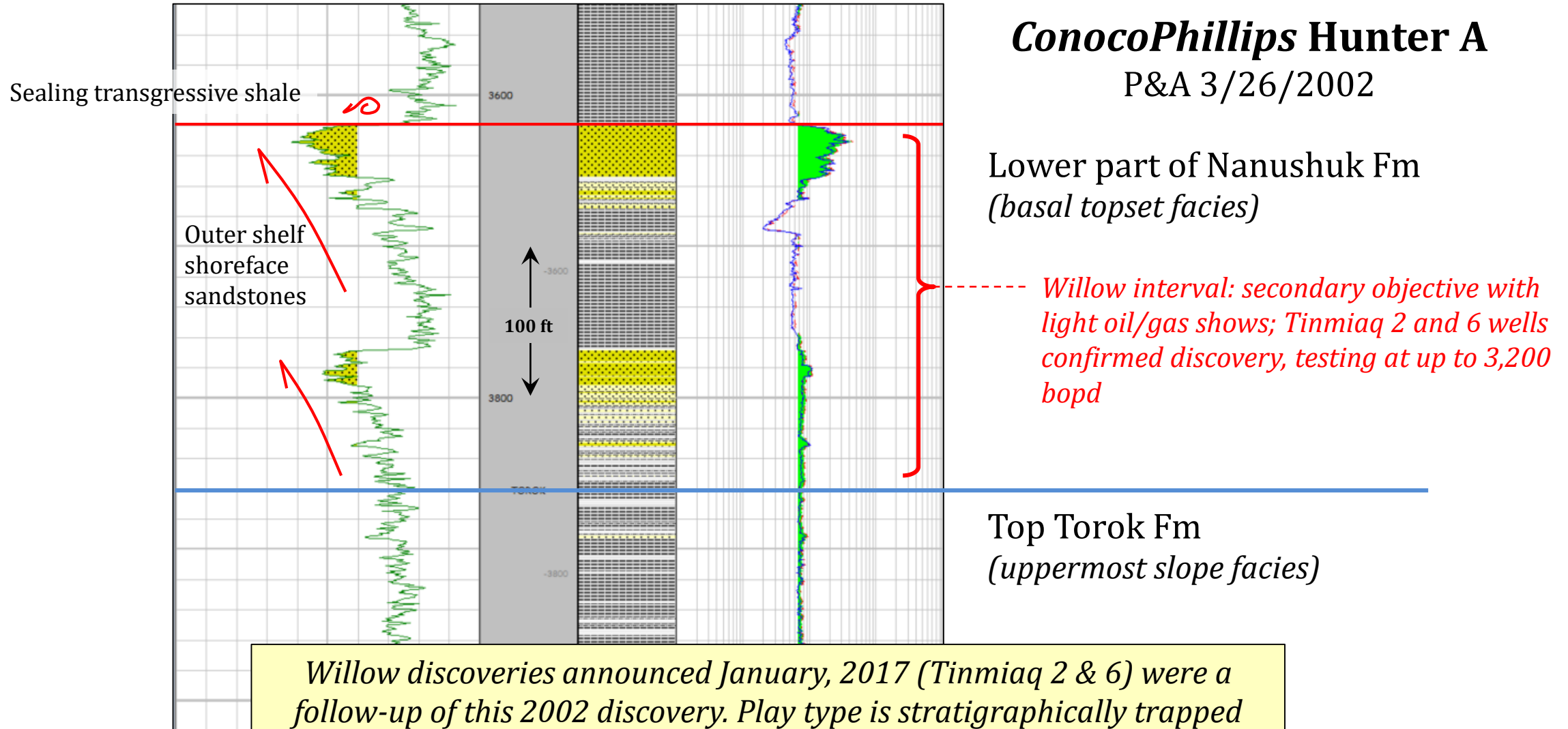
# NANUSHUK SHELF-MARGIN ANOMALIES

## - NORTHERN NPRA -



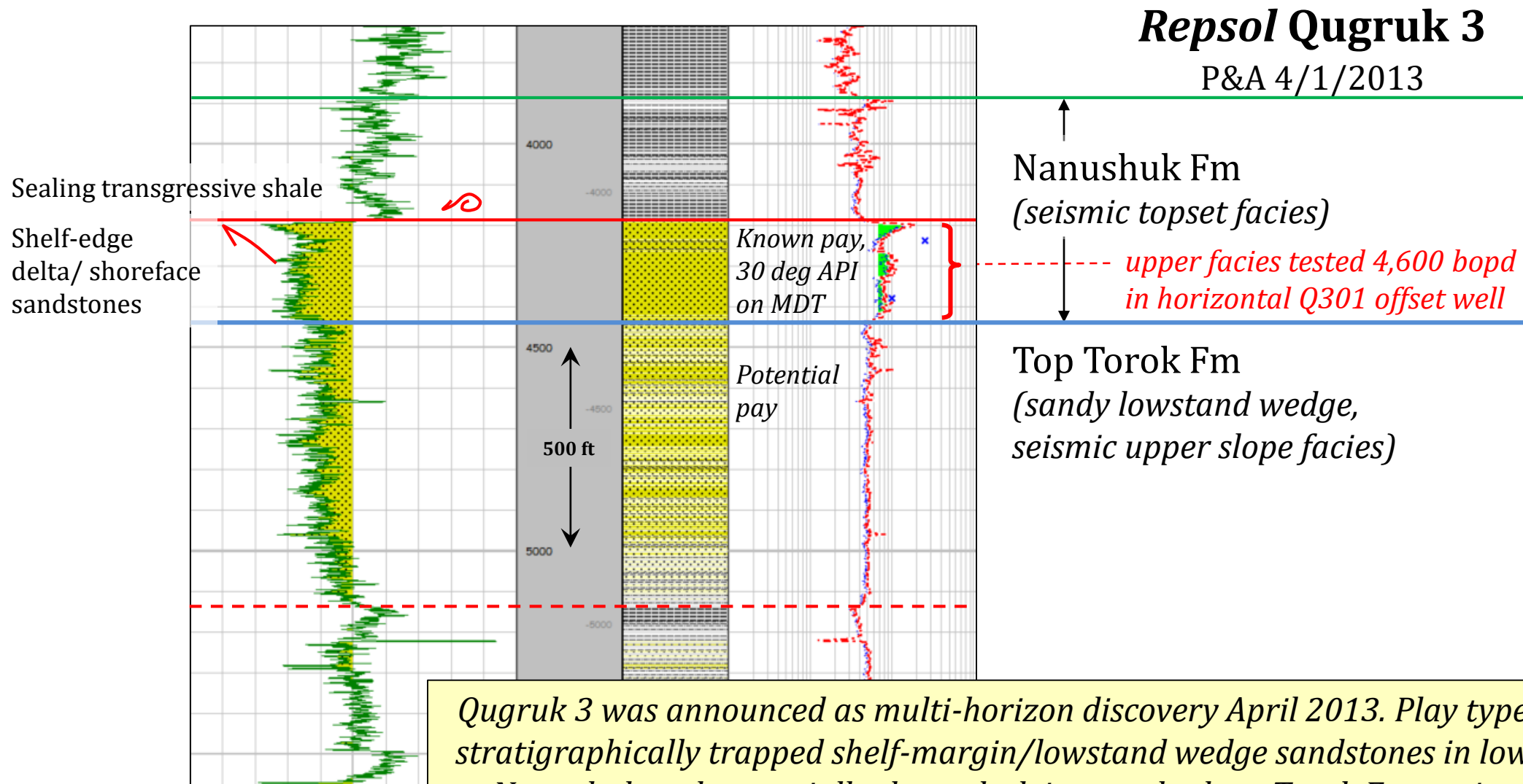
*Image courtesy L. Niglio and others , 2011 (BLM, BOEM)  
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# INITIAL WILLOW DISCOVERY - NANUSHUK FM



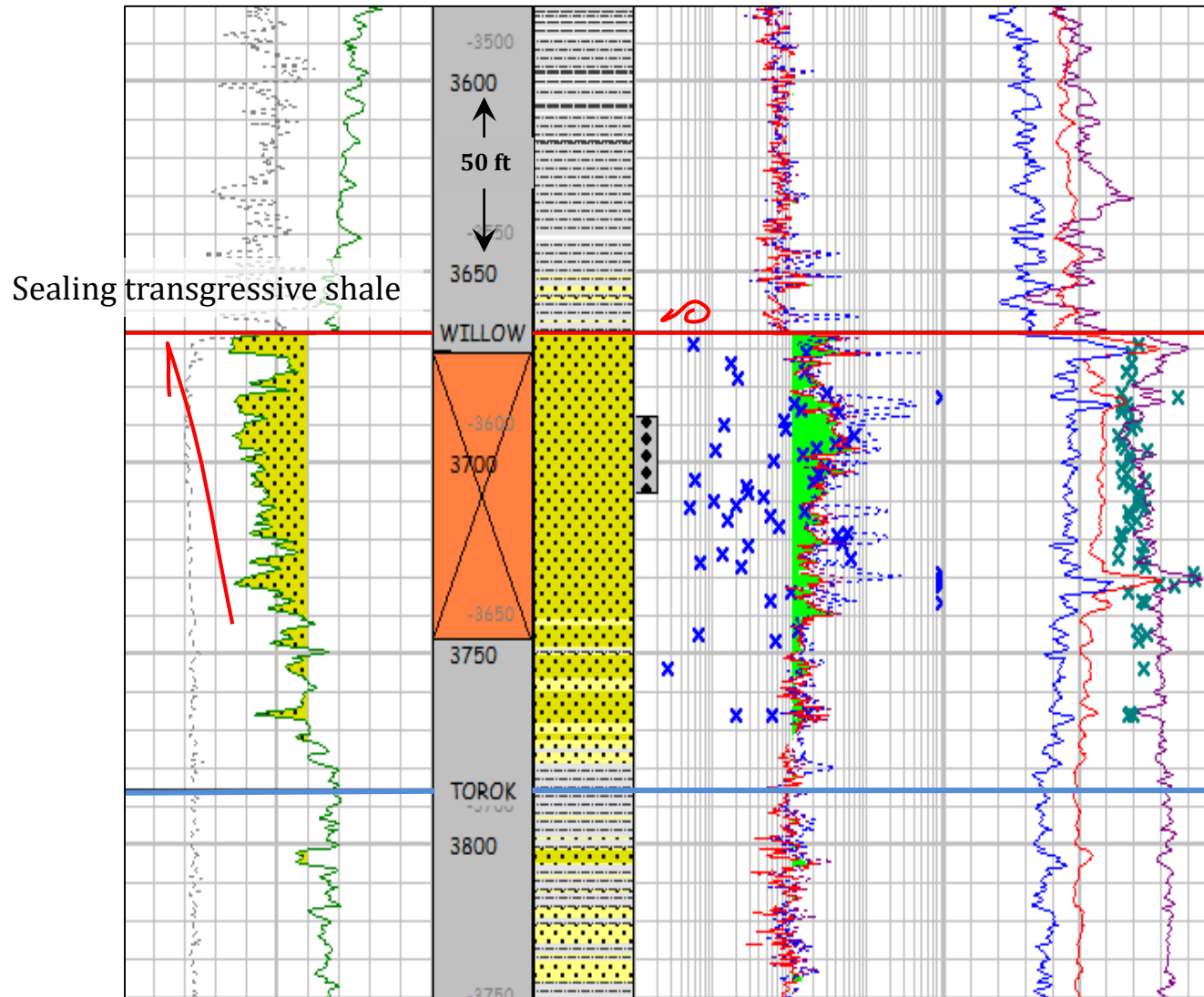


# PIKKA DISCOVERY TYPELOG - NANUSHUK FM



Qugruk 3 was announced as multi-horizon discovery April 2013. Play type is stratigraphically trapped shelf-margin/lowstand wedge sandstones in lower Nanushuk and potentially the underlying sandy slope Torok Formation.

# WILLOW TREND - NANUSHUK FM



## ConocoPhillips Tinmiaq 2

Suspended 03/02/2016

Lower part of Nanushuk Fm  
(basal topset facies)

### Willow Interval Core & Test

- Upper very fine sand to silt, average is coarse silt.
- Porosity avg = 17% (core)
- Permeability avg = 11 md (core)
- Flowed 3,220 bopd (41-45 API), 1.26 mmscf/d

Top Torok Fm  
(uppermost slope facies)

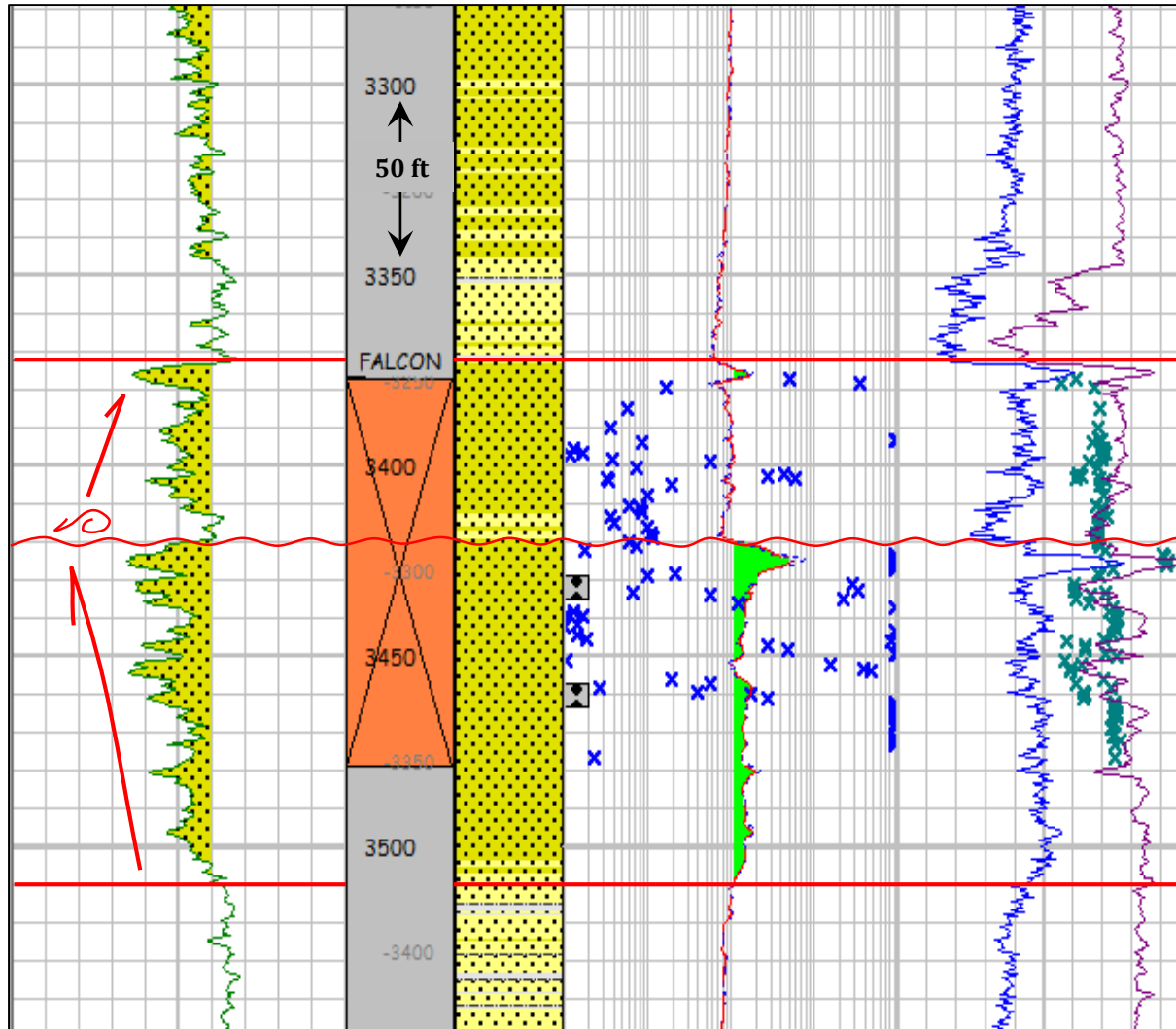


# WILLOW DISCOVERY - NANUSHUK FM

## **ConocoPhillips Tinmiaq 6**

Suspended 03/22/2016

Lower part of Nanushuk Fm  
(topset facies)

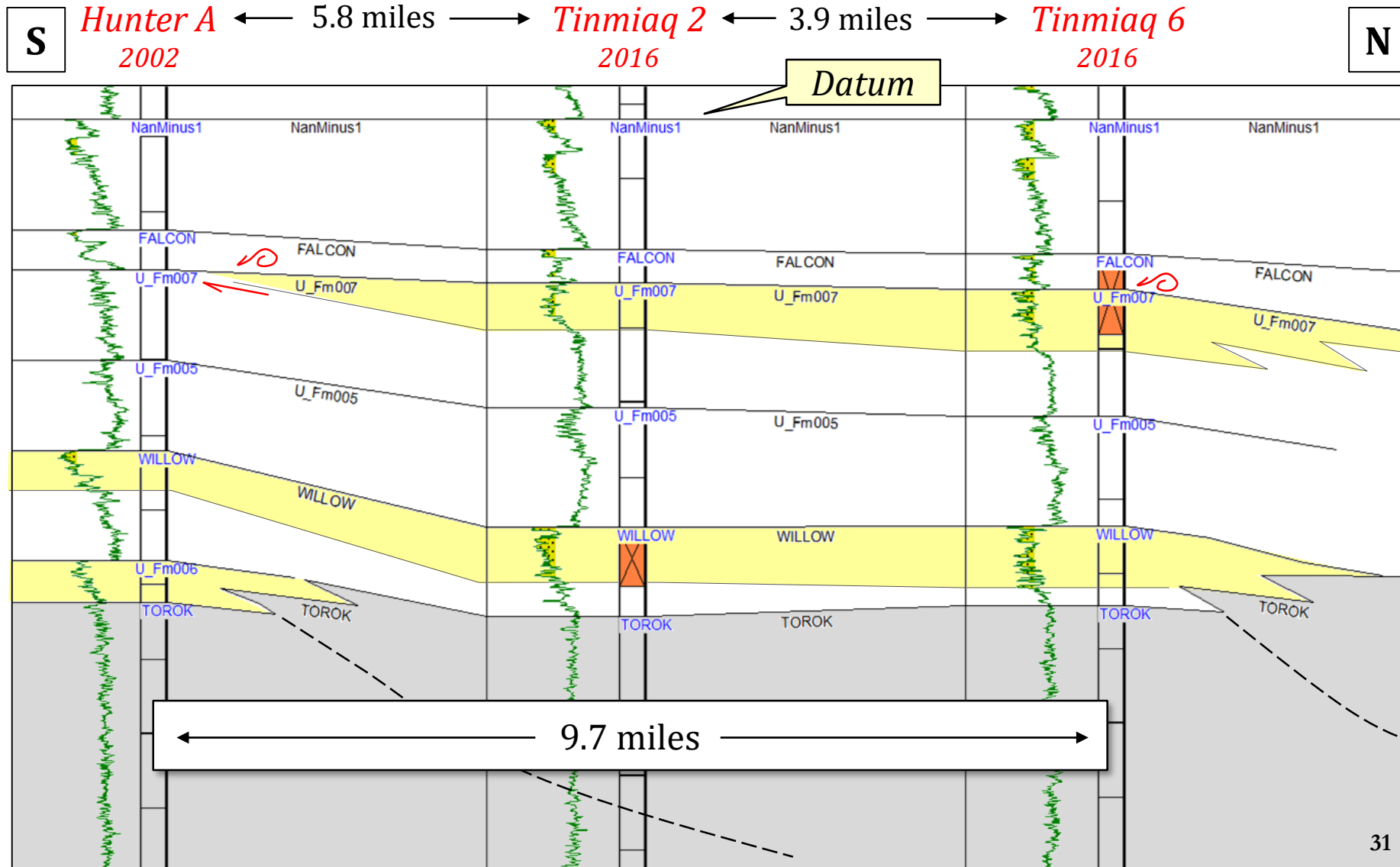


### ***Falcon Interval Core & Test***

- *Very fine to fine sand, overlain by silt*
- *Porosity avg = 18%*
- *Permeability avg = 18 md*
- *Flowed 1,000 bwpd, trace oil (42 API), gas too small to measure*
- *Tight transgressive surface within interval(?) Sealing?*

# RESERVOIR CONTINUITY ALONG STRIKE

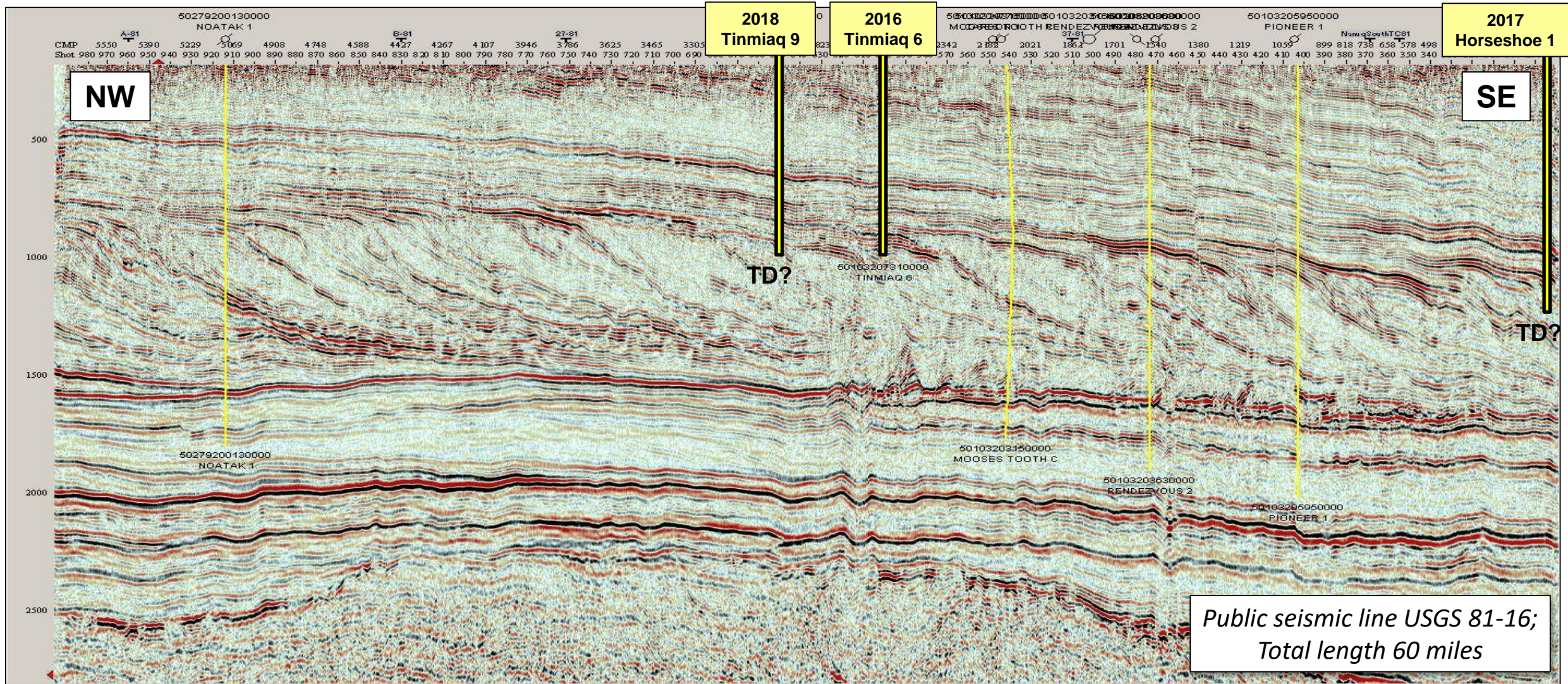
## - WILLOW AND FALCON INTERVALS -





# HAVE WE SEEN JUST THE TIP OF THE ICEBERG?

- WILLOW, HORSESHOE TRENDS AMONG MANY MORE -





# UNDISCOVERED RESOURCES

- USGS and BOEM are actively reassessing Arctic Alaska's undiscovered, technically recoverable conventional resources:
  - As of December 2017, interim revisions raise the mean estimate for all of Arctic Alaska by ~9 billion barrels to nearly 50 billion barrels of oil + natural gas liquids (NGL), ~evenly split between onshore and offshore.
- The Nanushuk topset play in the central and western North Slope is far more prospective than previous resource assessments recognized:
  - For example, at 300 million barrels recoverable, the Willow discovery alone far exceeds even the 2010 USGS upside estimate (F5 case) for the entire Stratigraphic Brookian Topset play in NPRA.
  - By itself, the Nanushuk Fm play (NPRA, state lands, and nearby OCS) is now assessed with a mean of 7.3 billion barrels of undiscovered oil + NGL.



# RECAP – KEY POINTS

- Proven petroleum system for very large Shublik and HRZ(?) oil accumulations in basal Nanushuk Fm stratigraphic traps:
  - ✓ *Reservoir quality sands and strat traps developed in response to repeated sea level fluctuations*
  - ✓ *Source rocks are at early to peak maturity in Barrow Arch province; effective oil migration to lower Nanushuk from both sources*
- Play has plenty of running room to west; gas risk and leasing access are potential constraints.
- Recent USGS assessment volumes reflect the significance of this newly proven world-class play

# NANUSHUK TOPSET PLAY

- FOOTHILLS OUTCROP ANALOGUE, SLOPE MOUNTAIN -

