Integrated Application of Seismic Attributes and Petrophysical Modeling of the Nanushuk and Torok Formations on the North Slope, AK: Implications for Supersized Oilfield Development

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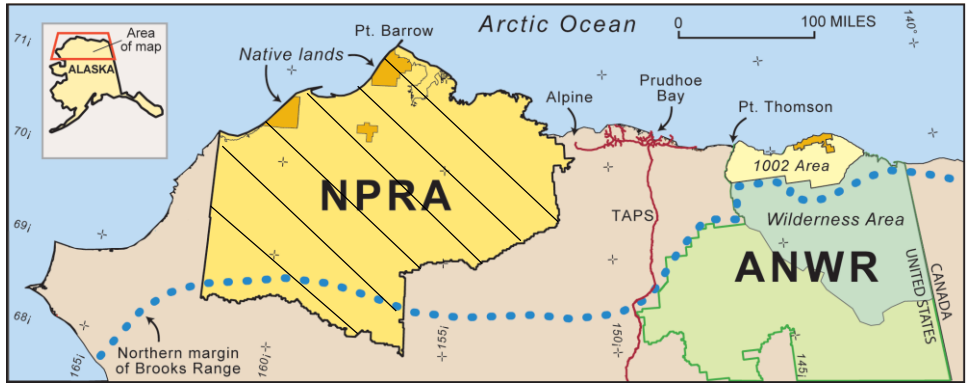
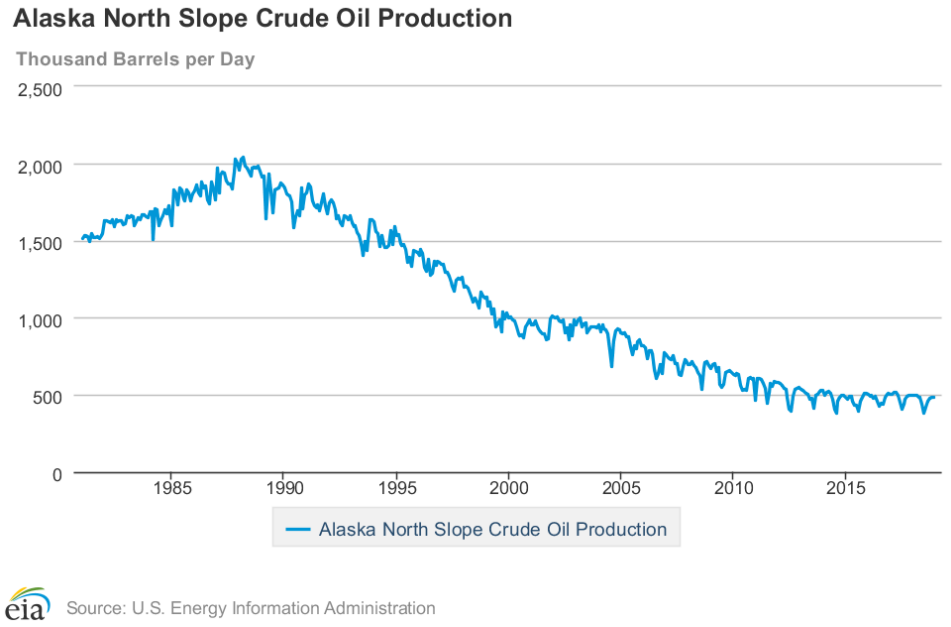
Project Background

- Study area: North Slope, Alaska
- Producing hydrocarbons over the last five decades from the Prudhoe Bay, Milne Point, and Kuparuk River oil fields
- As per IHS, the North Slope is one of the superbasins in the world.
- A majority of the oil fields are deep and defined by structural traps related to extensional faults.
- The hydrocarbon production is in decline since 1990s.



Location of the study area (shaded area- NPRA, ~37,000 sq. miles)

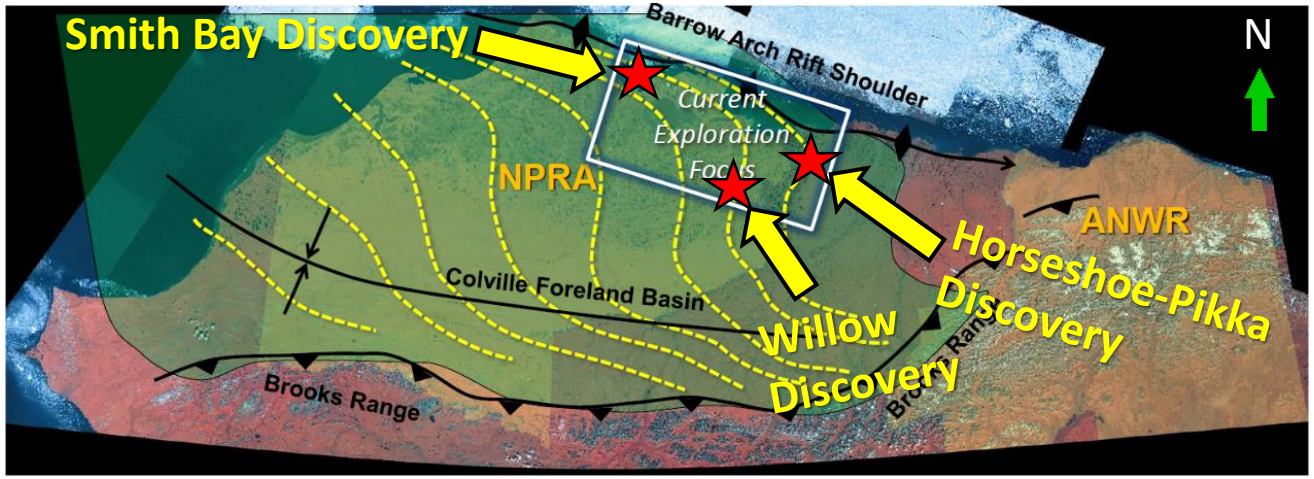


However,

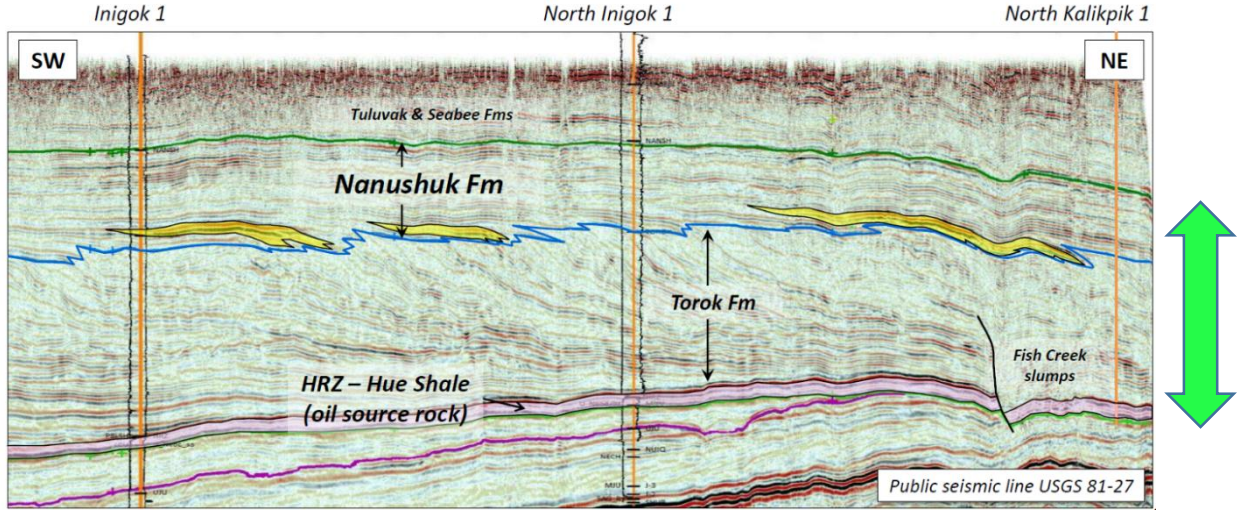
- **Three major discoveries** have been made in one stratigraphic sequence in the last few years.

1. 2015- Armstrong-Repsol, Pikka discovery, recoverable: ~300 MMBO
2. 2016- Caelus Energy, Smith Bay discovery, recoverable: ~1.2 BBO
3. 2017- ConocoPhillips, Willow discovery, recoverable: ~750 MMBO

- All these discoveries have been made either in the Nanushuk topsets or its time-equivalent Torok turbidities.
- As per USGS (2017), 8.7 BBO of recoverable oil and 25.2 TCF of gas in the Nanushuk-Torok formations

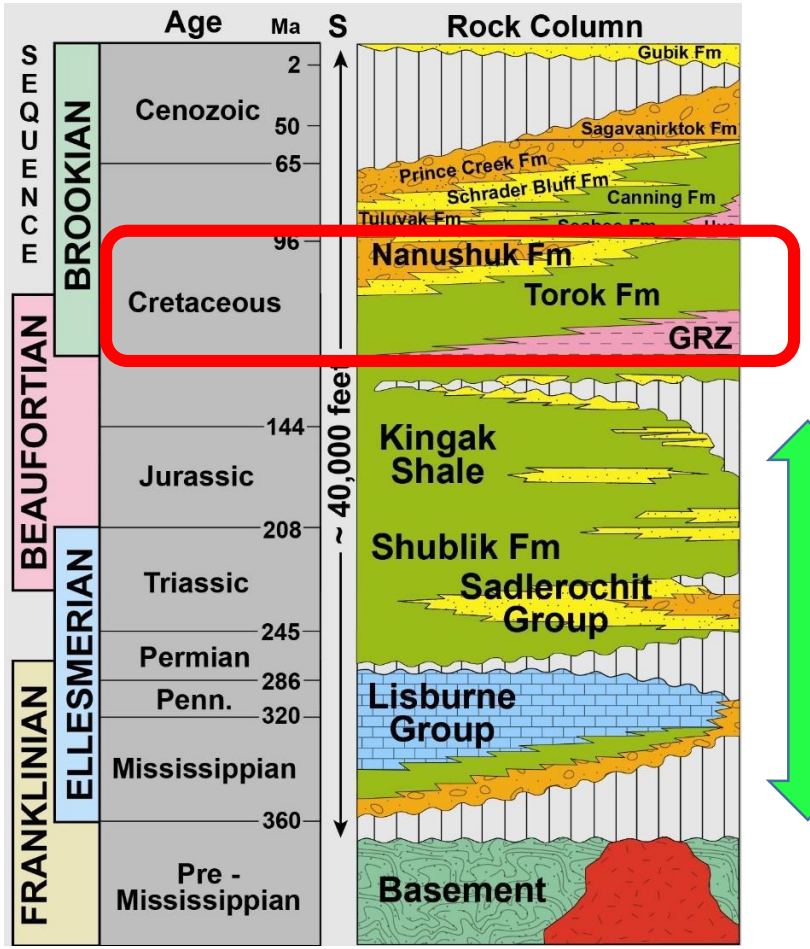


Current exploration focus (yellow lines indicates the clinoforms orientations, and stars indicate discoveries, after Decker, 2018)



Nanushuk-Torok on a seismic section (after Decker, 2018)

Geology of the Nanushuk-Torok Formations

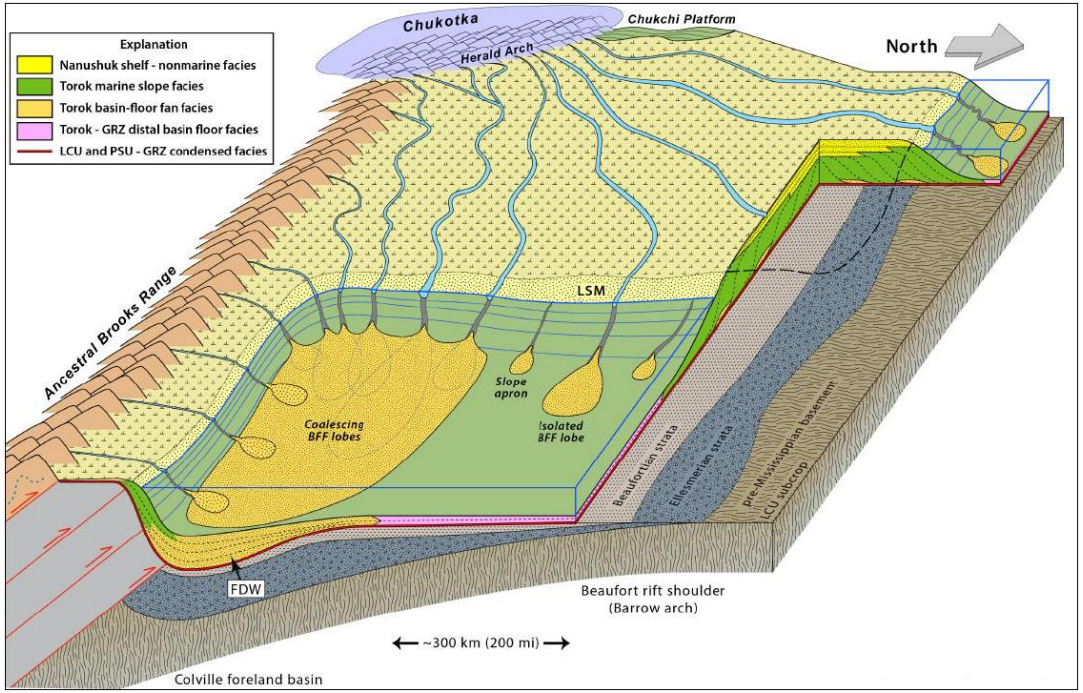


New Discoveries

Producing Formations

Stratigraphic Column on the North Slope (after Garrity et al., 2005)

Conceptual Depositional model

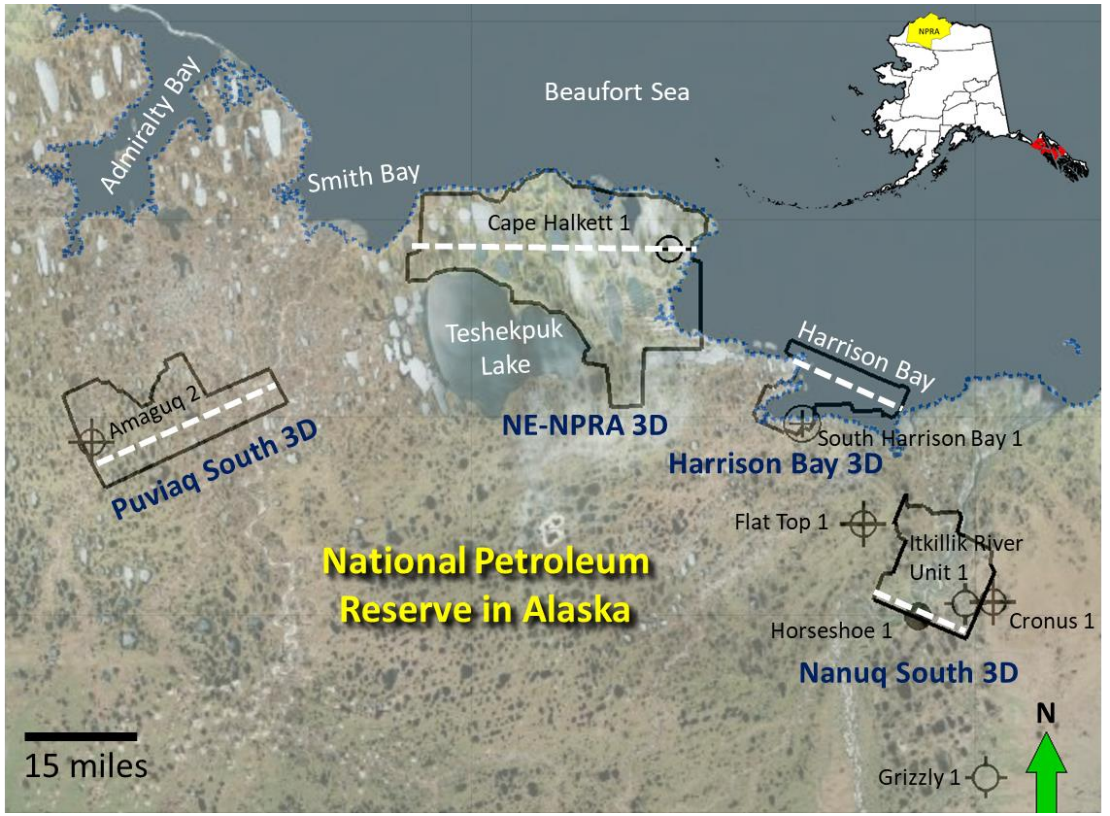


Generalized depositional model of the Lower Cretaceous clinothems of the Nanushuk-Torok formations (after Houseknecht, 2019).

Goals

1. Identify the complex geomorphological features in the Nanushuk-Torok formations

2. Detect the reservoir intervals in the Nanushuk-Torok formations

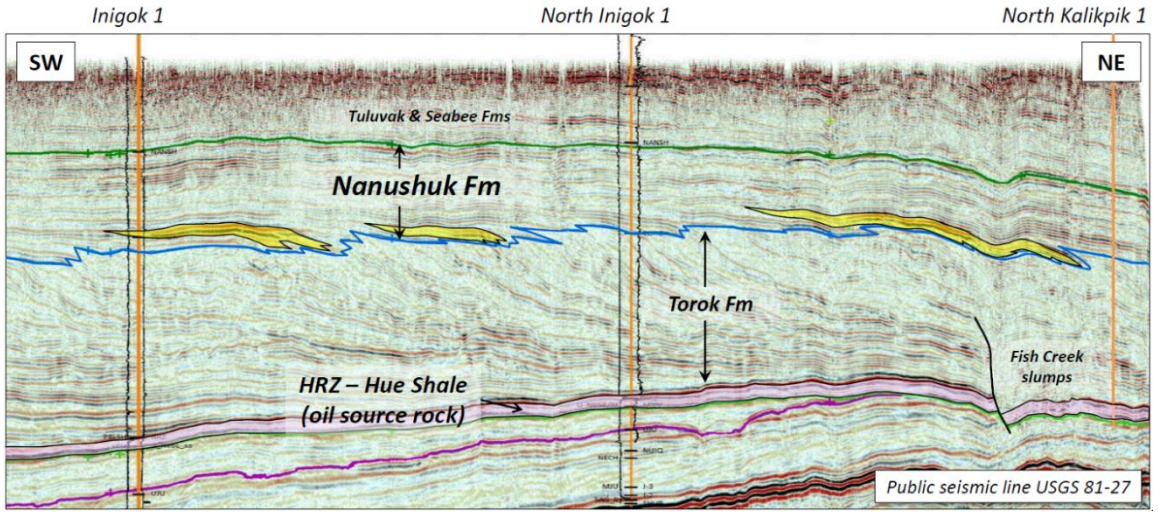


Location of the study area with available data. The four polygons show the locations of the 3D seismic surveys in the NPRA. Dash lines indicate the seismic sections. Total area of the NPRA: ~37,000 sq. miles

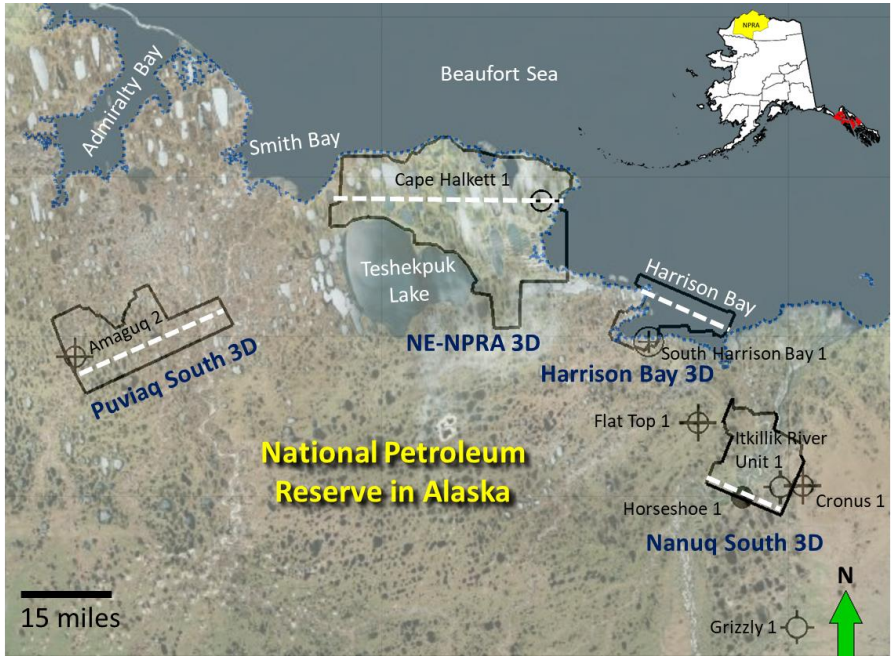
After Bhattacharya and Verma, 2019

Available Data

1. Several 3D seismic surveys over approx. 1,200 square miles (mostly post-stack data used in the current work)
2. Multiple wells with common and advanced petrophysical logs
3. Core (e.g., poro-perm, velocity, and XRD/XRF)

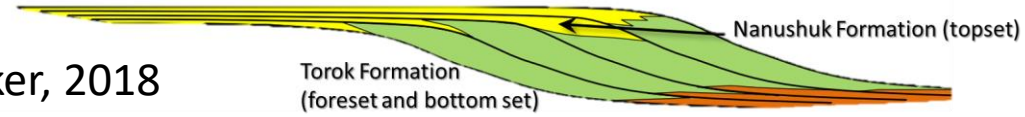


A seismic line along NE-SW (after Decker, 2018)



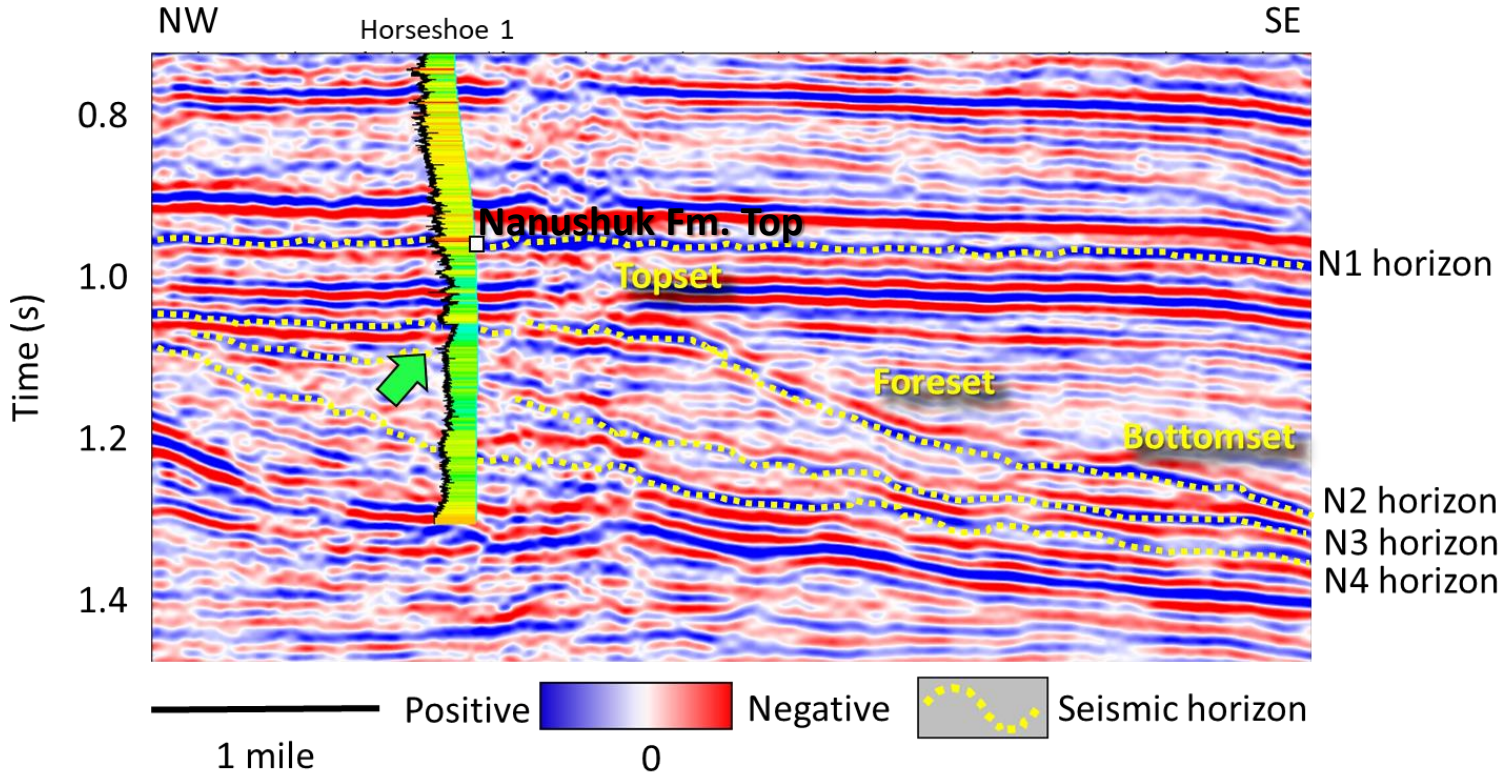
Location of the study area with available data

On Outcrop and Seismic Data



Decker, 2018

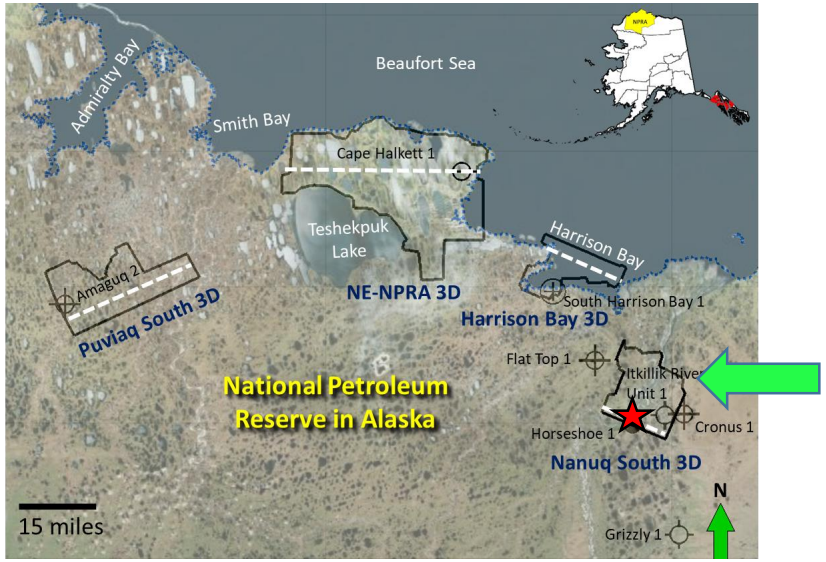
Delineating the Shelf-edges using Seismic Data



A seismic section along NW-SE

Nanuq South 3D Survey
(near the Horseshoe/Pikka discovery)

- Low-angle clinoforms distributed over large area; however, the angle changes in different areas.
- Prograding shelf-edge (deltaic) deposits along N/NE-S/SW



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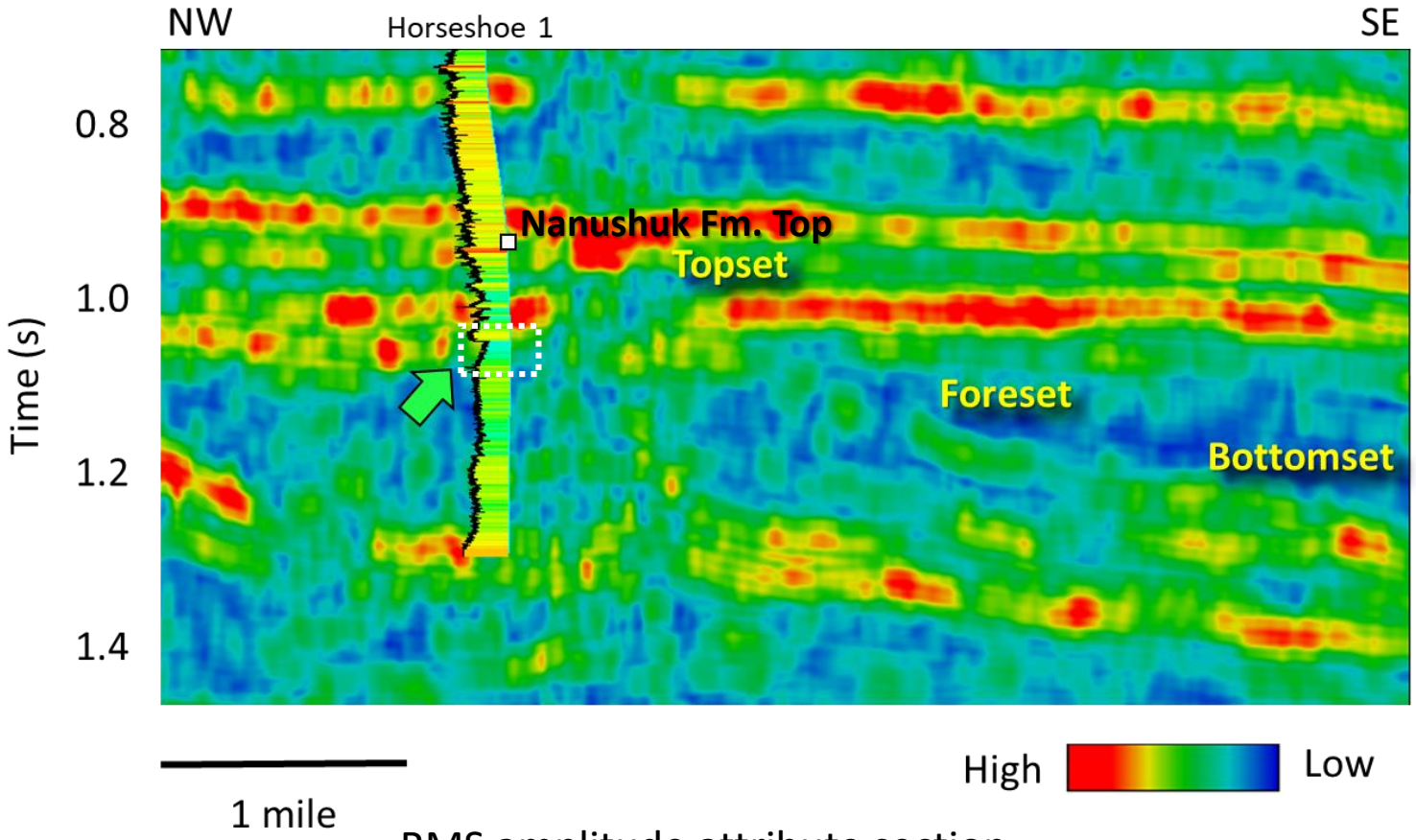
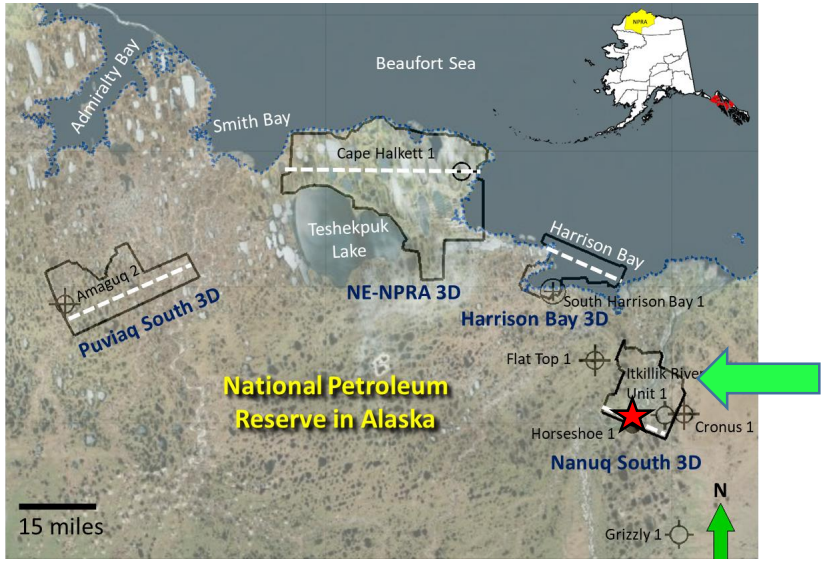
Seismic Amplitude Anomalies



RMS amplitude attribute section

- Amplitude anomalies: Nanushuk shelf-edges and topsets, and Torok foresets
- Work in progress: pre-stack seismic analysis and impedance inversion



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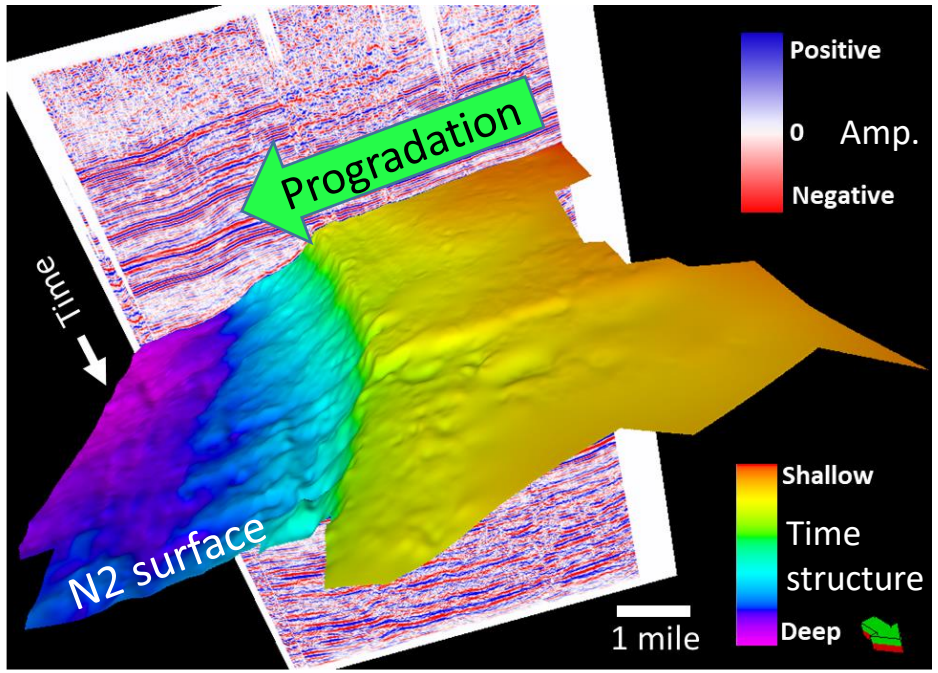
Nanuq South 3D Survey
(near the Horseshoe/Pikka discovery)

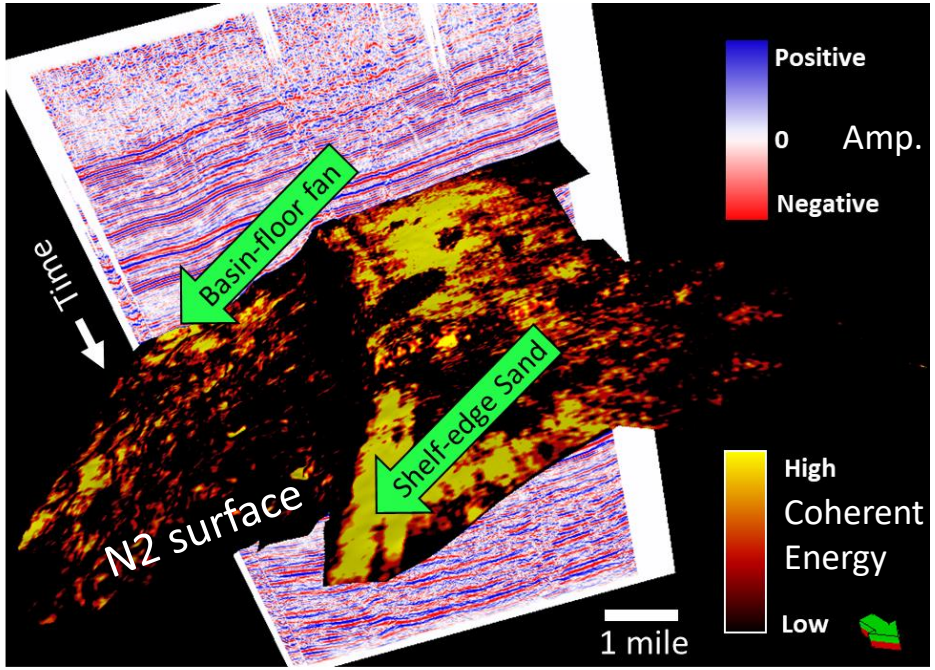
After Bhattacharya and Verma, 2019

Mapping the Shelf-edges



A seismic line showing low-angle clinoforms, N2 surface in 3D view (vertical exaggeration: 25)

- Several sequence boundaries mapped using the 3D seismic data
- Coherent Energy attribute shows the presence of high-energy deposits in two dominant forms:
  1. Laterally continuous on the shelf-edges
  2. Sporadically present on the basin-floor



Coherent Energy attribute on the N2 surface in 3D view

Nanuq South 3D Survey
(near the Horseshoe/Pikka discovery)

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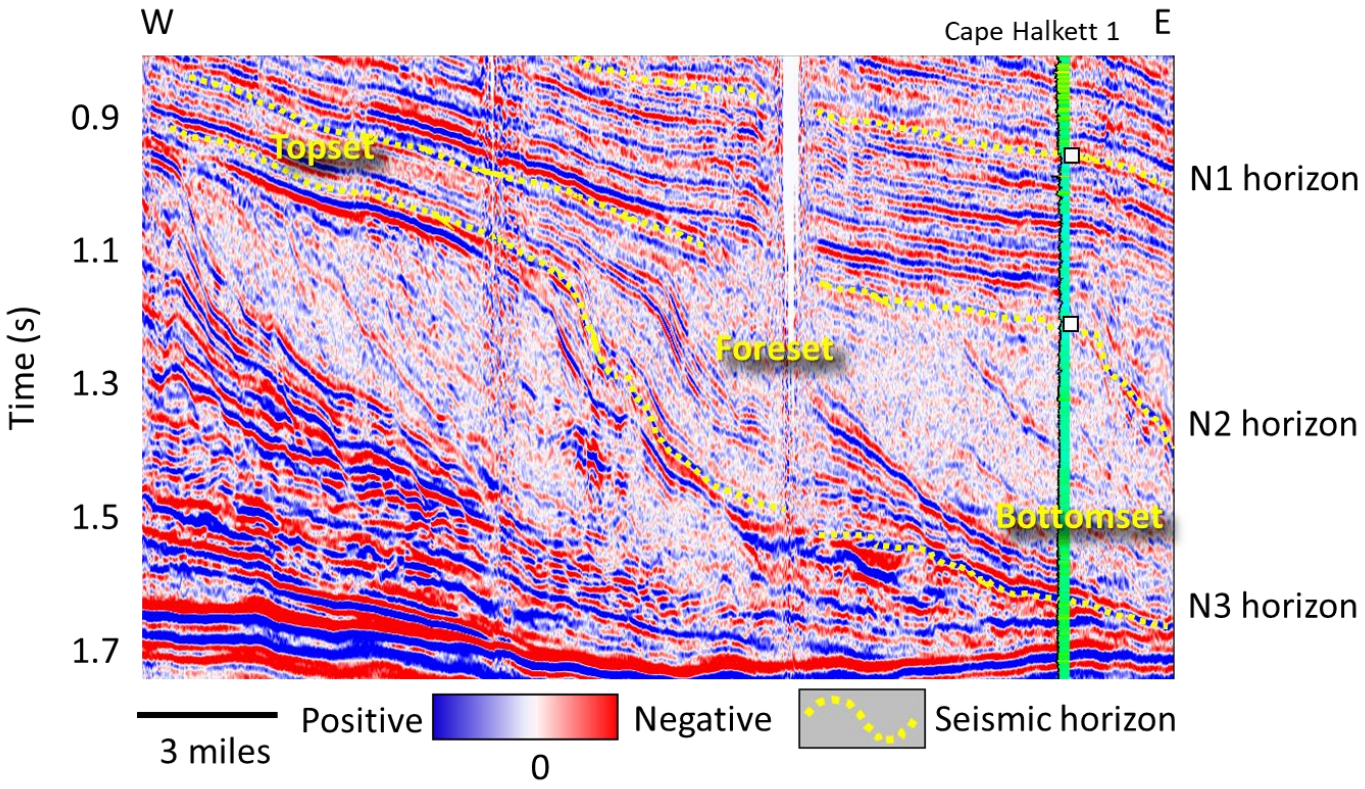
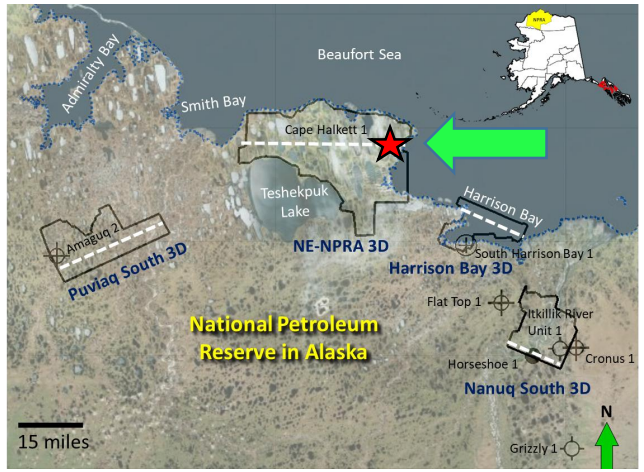
Seismic Geomorphology



A seismic section along E-W

- Moving NW, similar types of sequences were observed and mapped using another 3D seismic data.
- Low-angle clinoforms extend over 10s of miles.
- Several interesting geologic features, including shelf-edges, channels, slides, mass-transport deposits (MTD), and basin-floor fans



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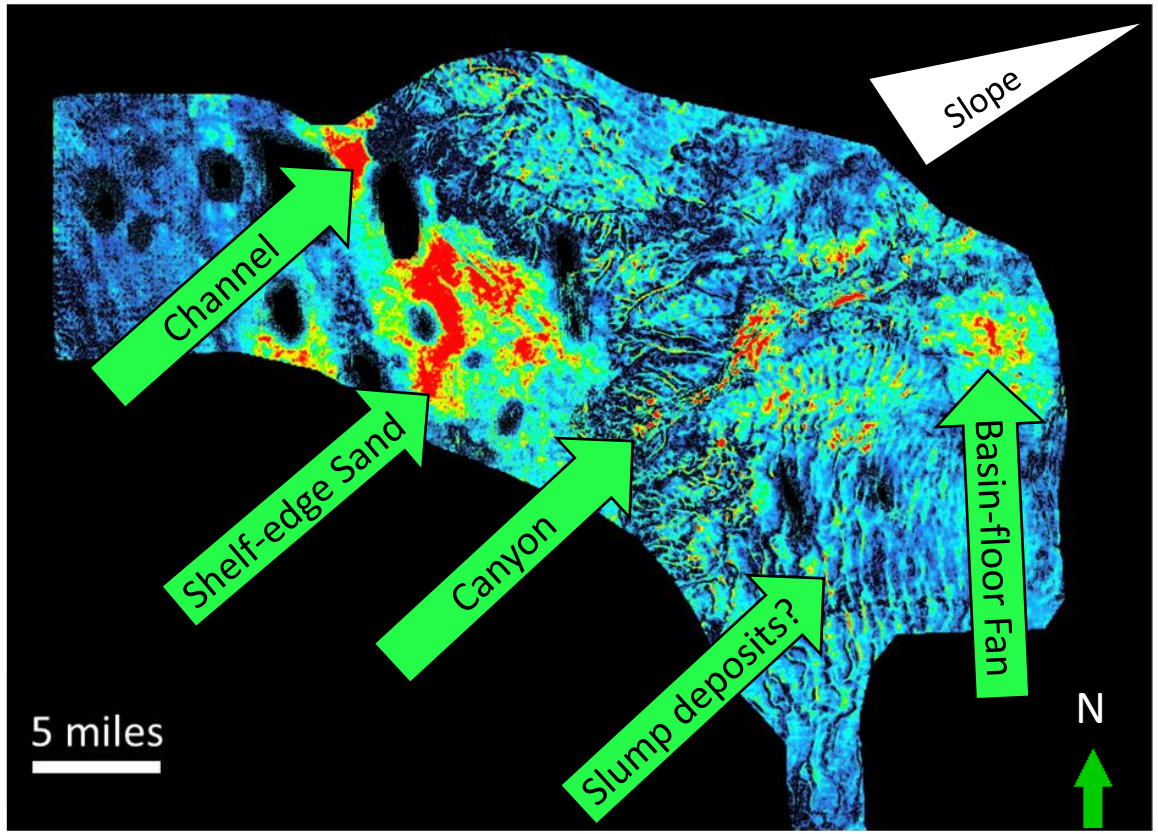
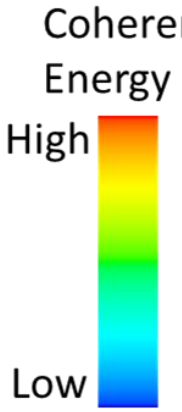
NE-NPRA 3D Survey
(near the Smith Bay discovery)

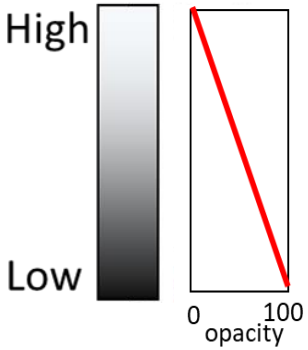
After Bhattacharya and Verma, 2019

Corendered Seismic Attributes on a Clinoform



Corendered seismic attributes (plan view)

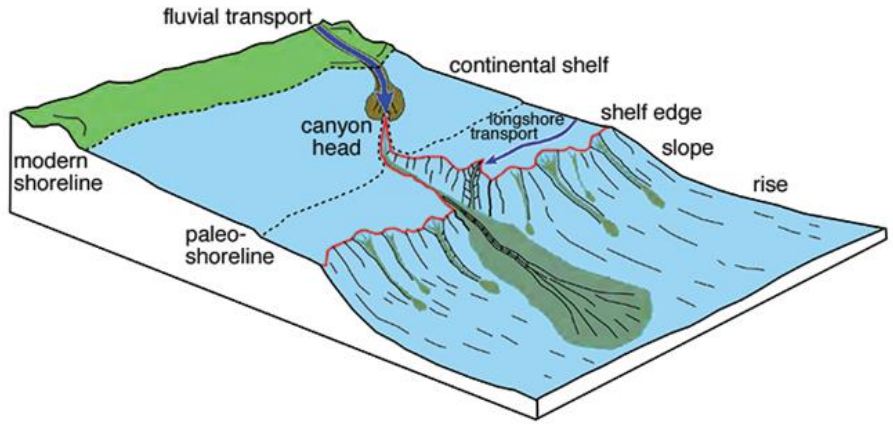




Corendered coherent energy and Sobel-filter similarity attributes illuminated important geologic features.

1. Shelf-edges,
2. Channels,
3. Basin-floor fans, etc.

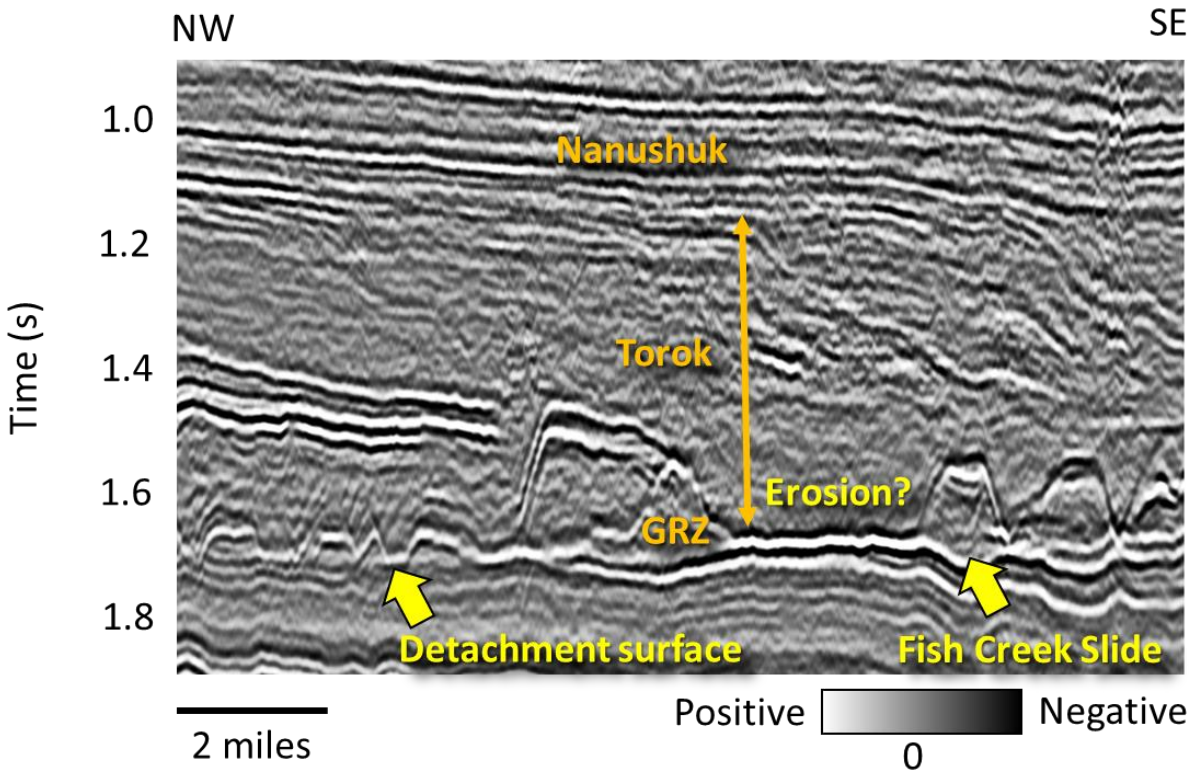
Conceptual depositional model



NE-NPRA 3D Survey
(near the Smith Bay discovery)

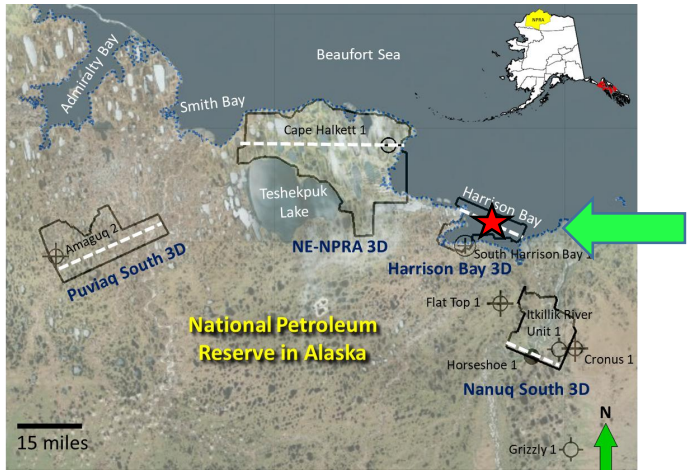
After Bhattacharya and Verma, 2019

Large Slides ("FLT") on the Seismic Sections



A seismic section along NW-SE

- Large slides (e.g., Fish Creek Slide) affect the Torok Formation at places.
- The low-velocity, organic-rich GRZ shale generates velocity push-down effect at several places.
- Productive wells have been drilled in the Jurassic and Cretaceous intervals, below the slides.



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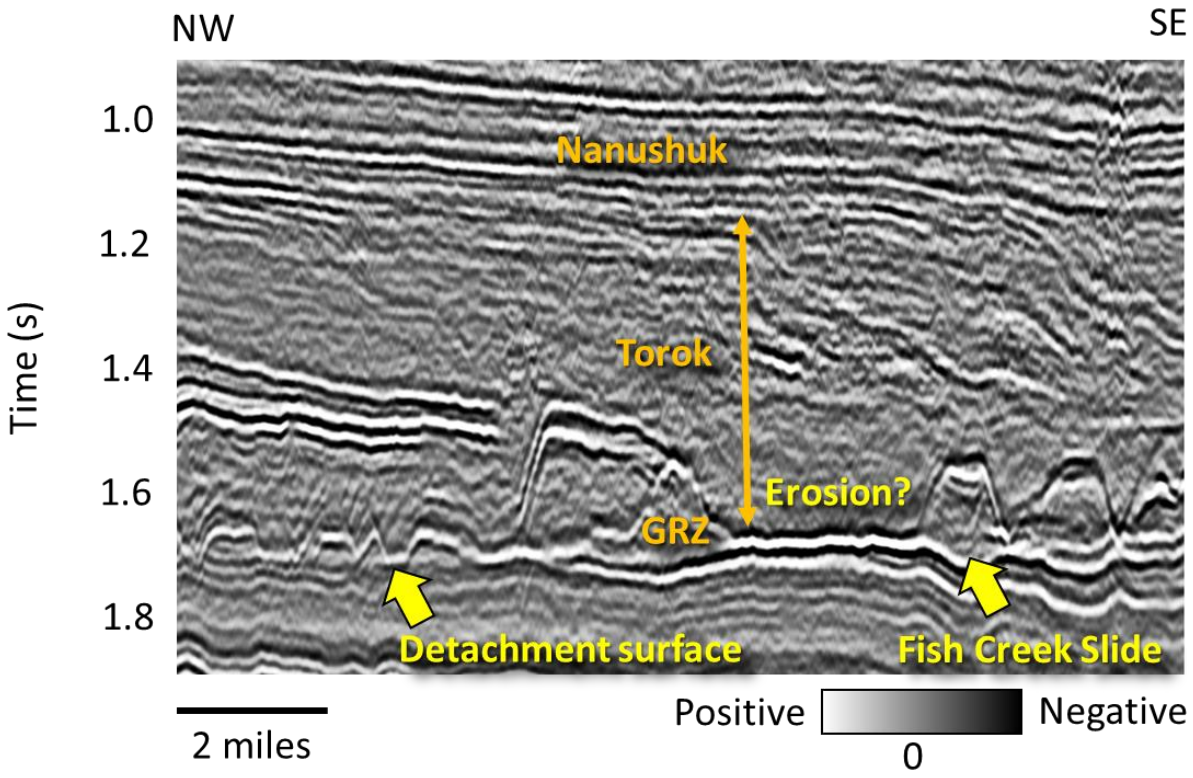
Harrison Bay 3D Survey

FLT: Funny Looking Things

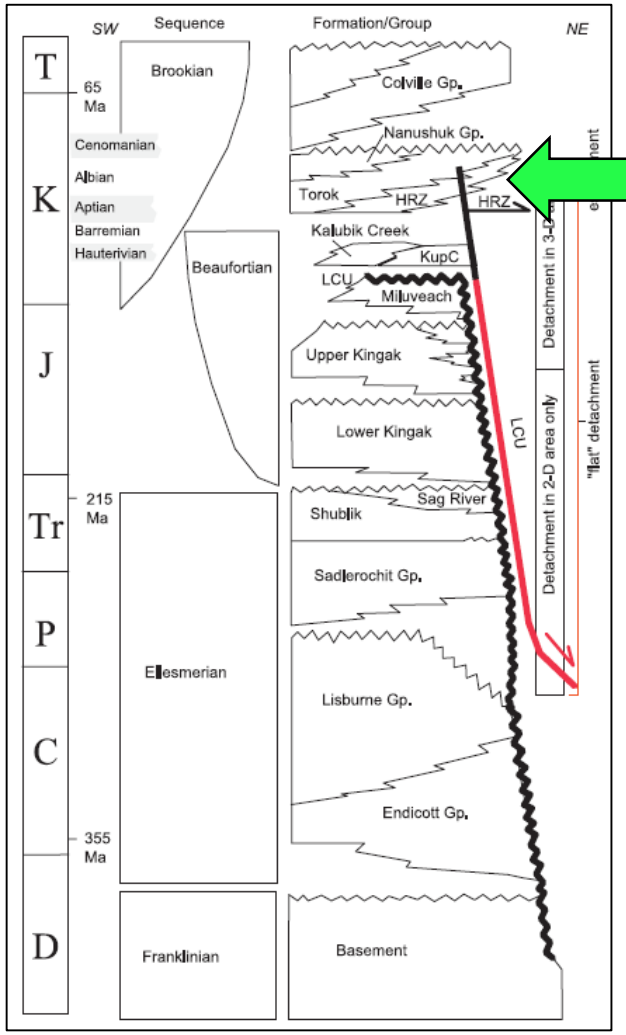
After Bhattacharya and Verma, 2019

Large Slides ("FLT") on the Seismic Sections



A seismic section along NW-SE

Harrison Bay 3D Survey

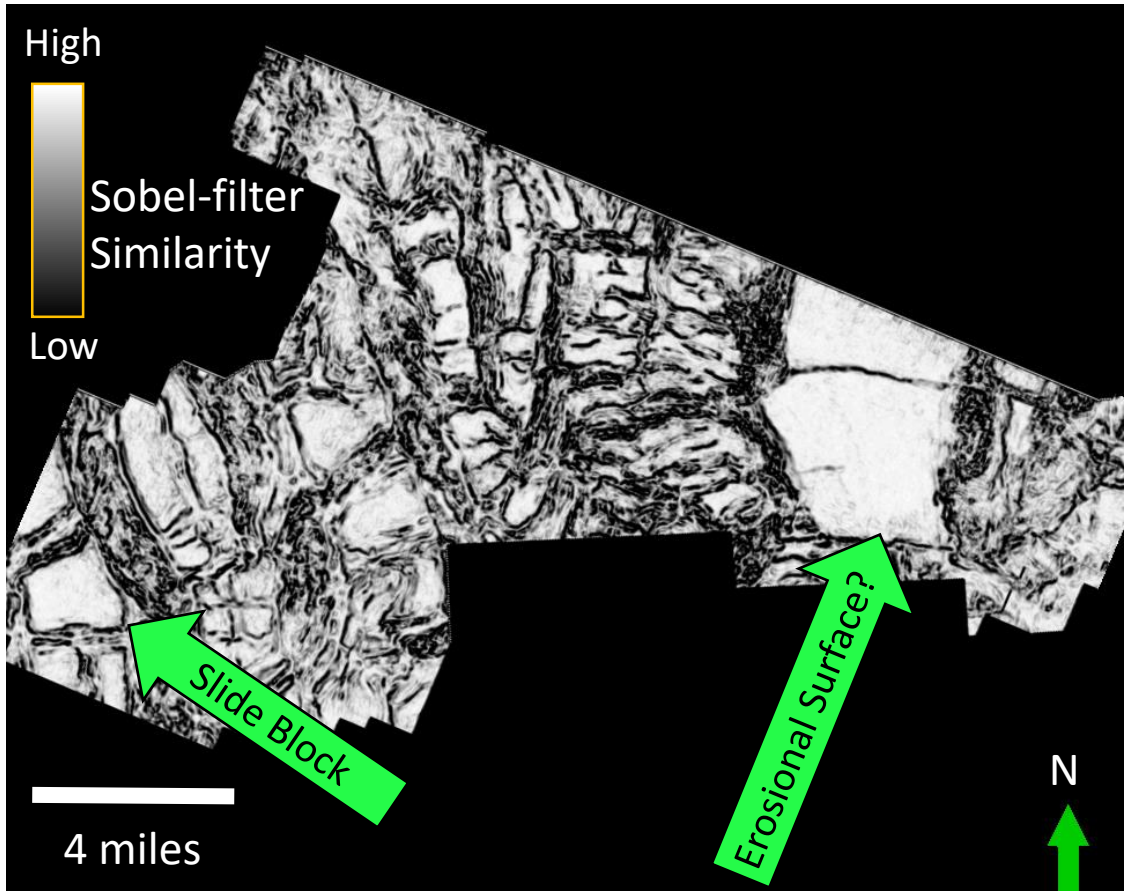


Thick black line shows the temporal extent of the Fish Creek Slide in terms of stratigraphy.

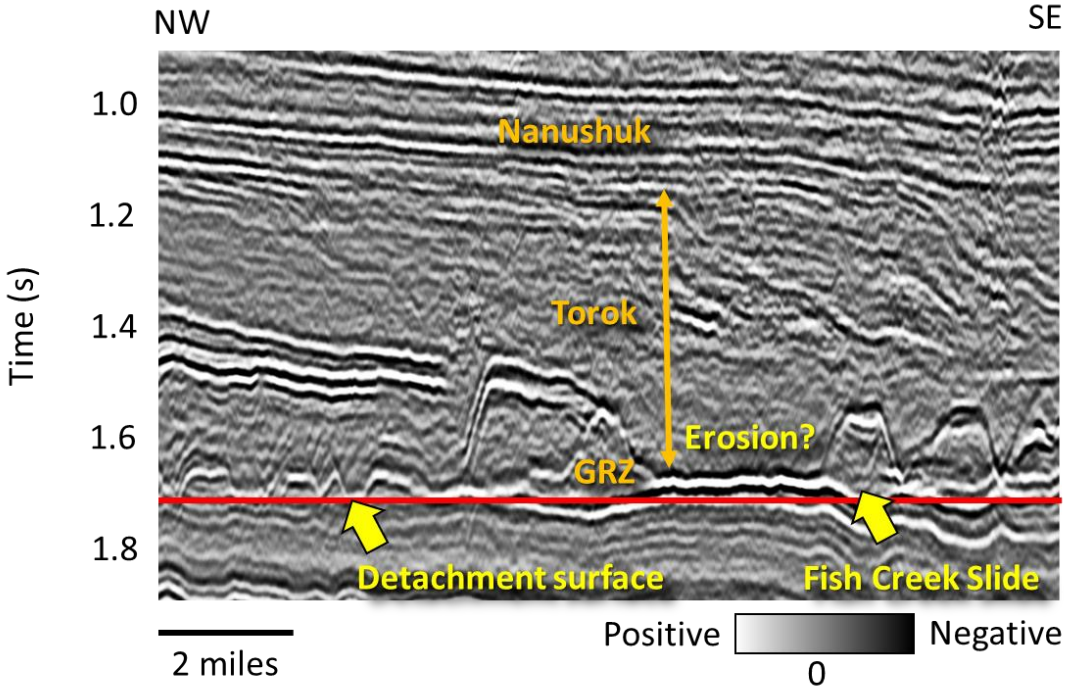
Homza, 2004

After Bhattacharya and Verma, 2019

Large Slides ("FLT") on the Sobel-filter Similarity Attribute



Sobel-filter similarity attribute on a time-slice near the GRZ shale horizon (red line on the seismic section)

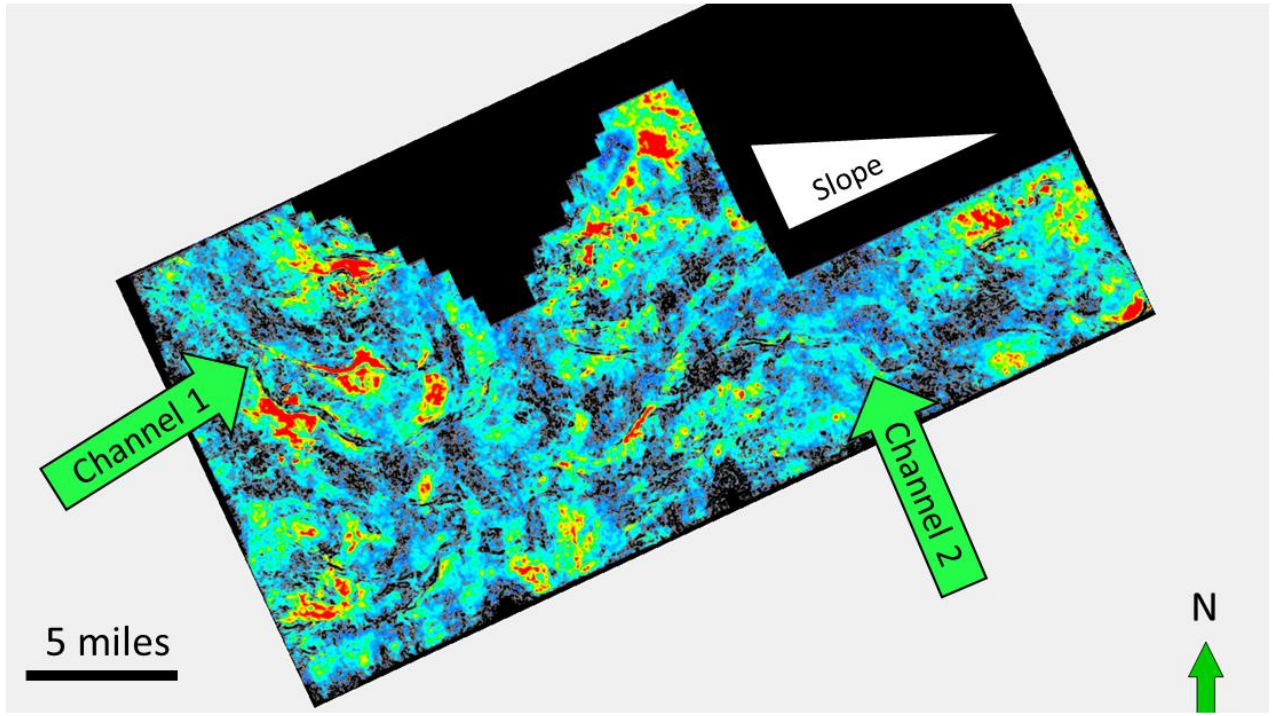


Slide blocks are arranged in different patterns (organized, disorganized, and isolated erosional remnants).

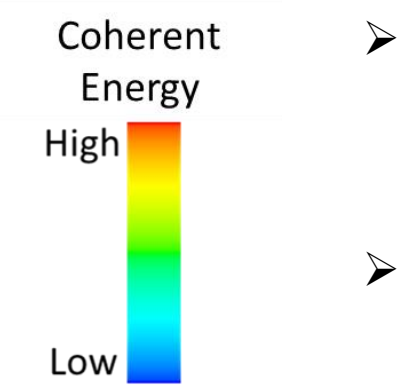
Harrison Bay 3D Survey

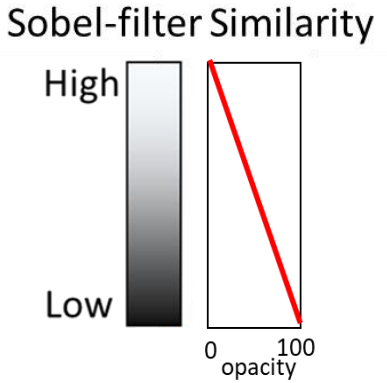
After Bhattacharya and Verma, 2019

Delineating Channels using Corendered Attributes

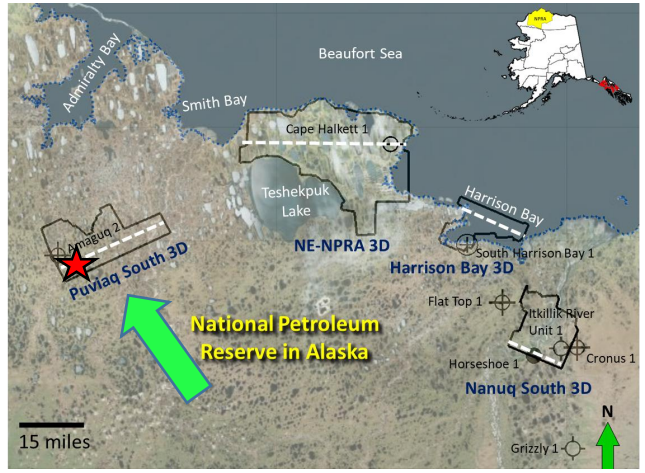


Identified channels on the corendered attributes (plan view)





- Channels found on the Nanushuk Formation and also along the slopes on the Torok.
- Corendered Sobel-filter similarity and coherent energy attributes help to delineate the channels.



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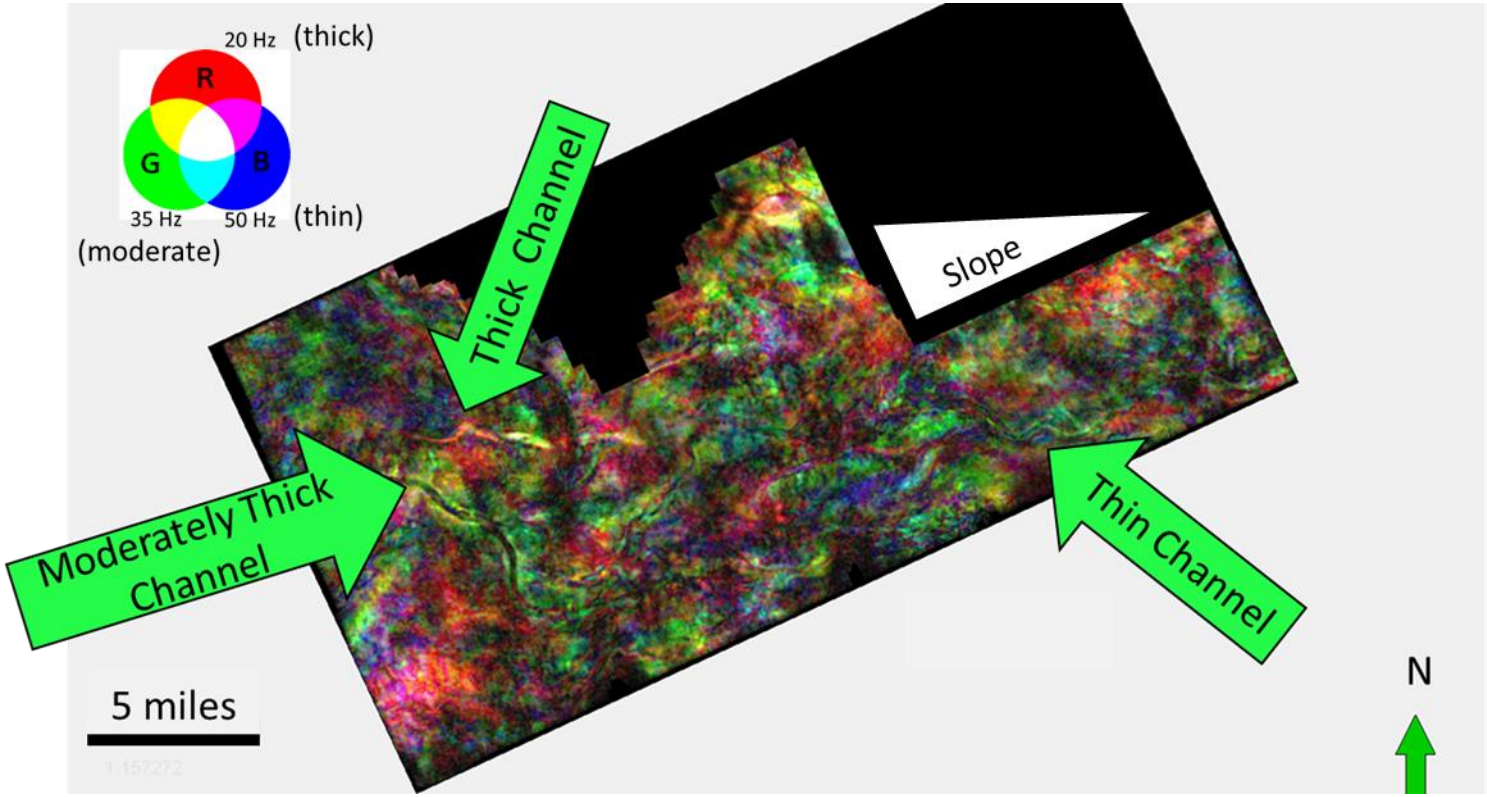
Puviaq 3D Survey

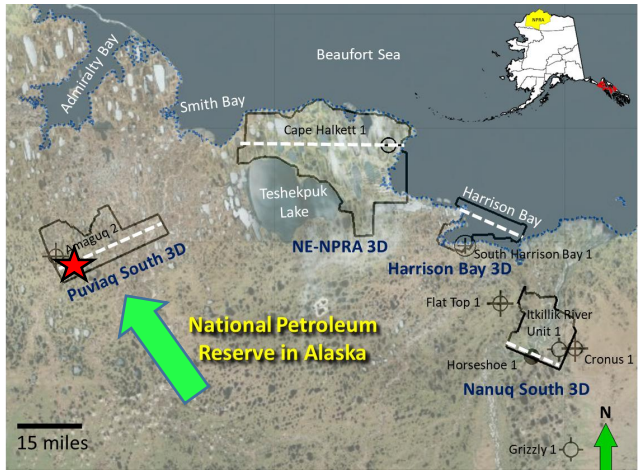
After Bhattacharya and Verma, 2019

Delineating Channels using Spectral Decomposition



Channels with different thickness (plan view)

- Different frequency elements correspond to thickness.
- Channels were found to be of variable thickness.
- Based on the velocity and frequency relationship, the approximate thickness: 78 ft.



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Puviaq 3D Survey

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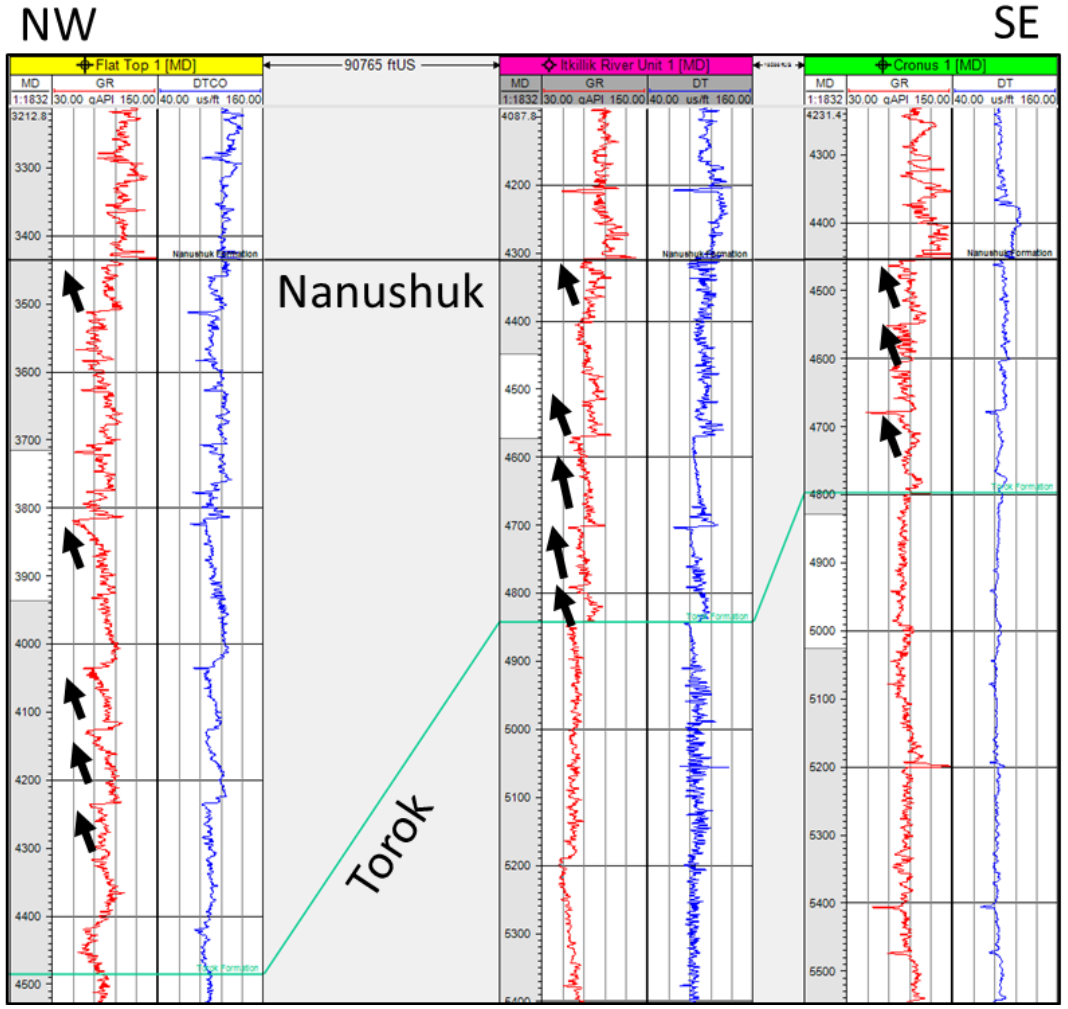
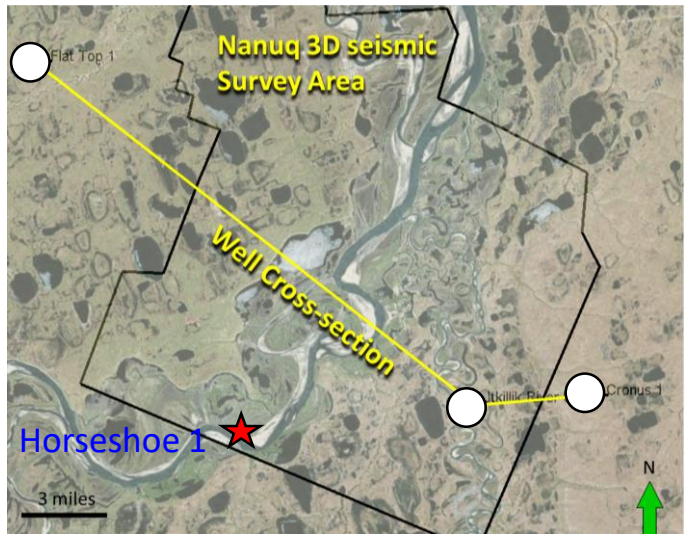
Well Log Correlation



- Multiple coarsening-upward sequences and shelf-edges
- Thickness of the Nanushuk Formation decreases toward the east as it is away from the shoreline.

Well log cross-section along NW-SE (near the Horseshoe-Pikka discovery).
Gamma (GR) log shown in the 1st track and sonic (DT/DTCO) log in the 2nd track.



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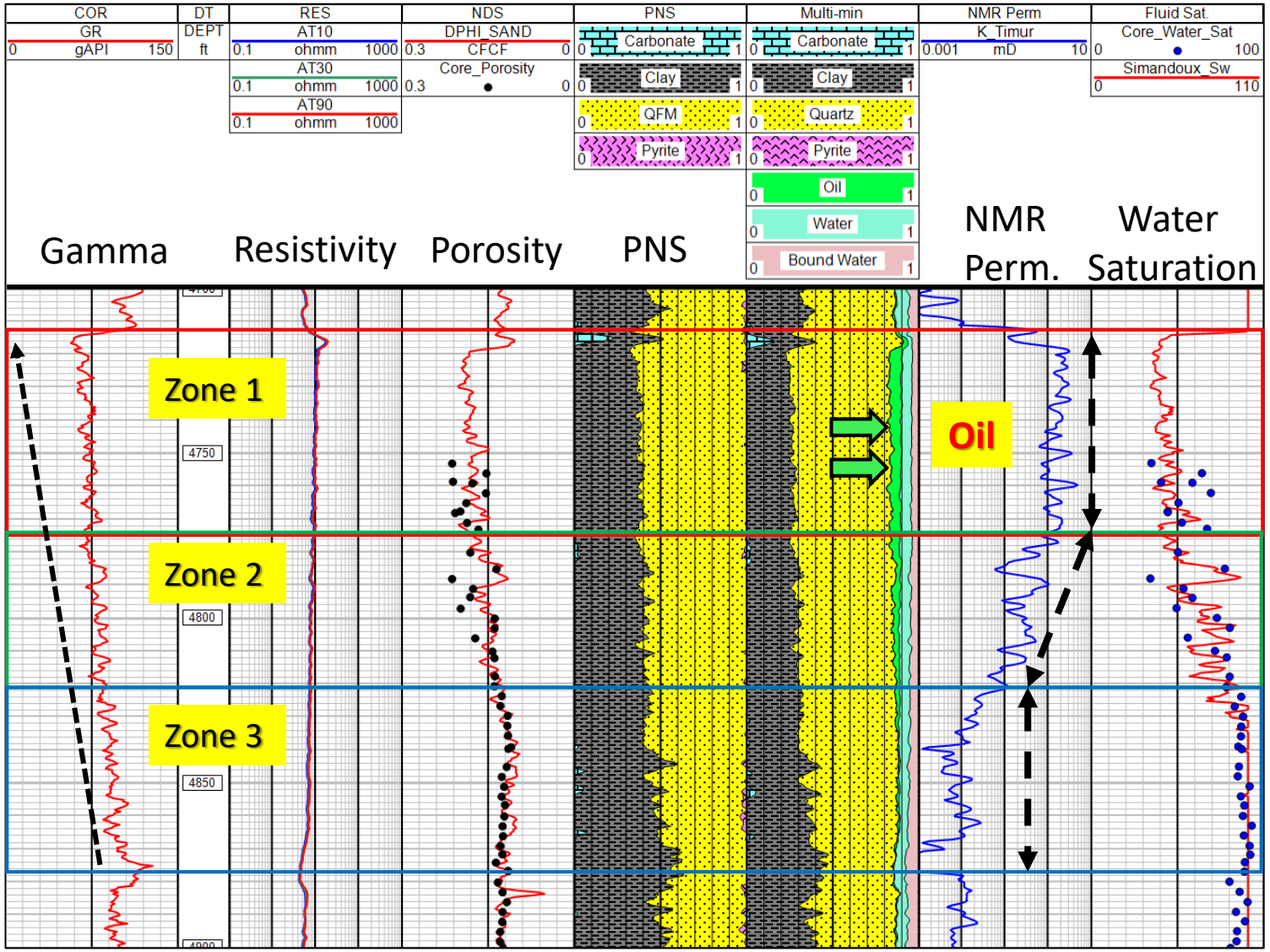
Advanced Petrophysical Analysis



- Detailed petrophysical analysis shows the vertical heterogeneity of the reservoir.
- Low-resistivity pay

1. Reservoir thickness: ~200 ft
2. Average porosity: 13-21%
3. Hydrocarbon saturation: 40-60%

➡ Modular Formation Dynamics Test (MDT)- Fluid sample (oil)

Horseshoe 1: Discovery well

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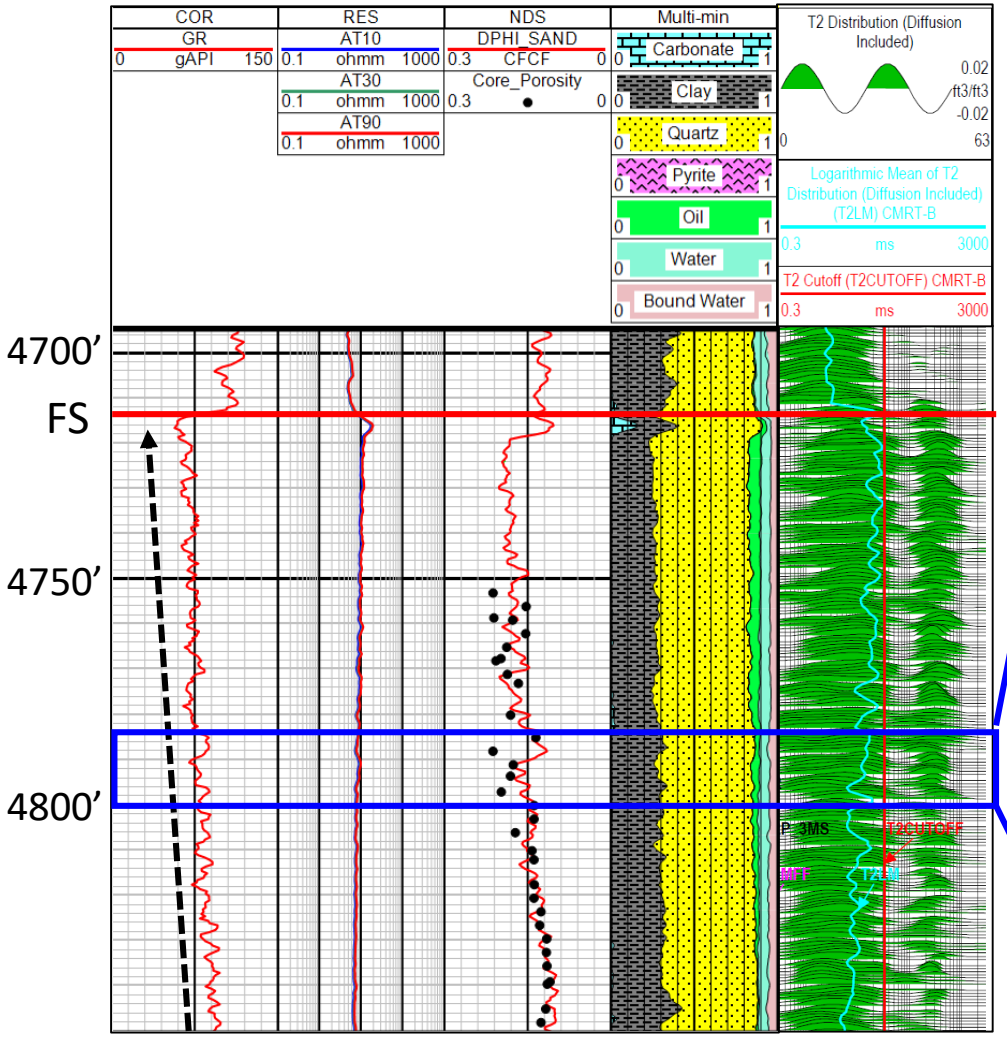
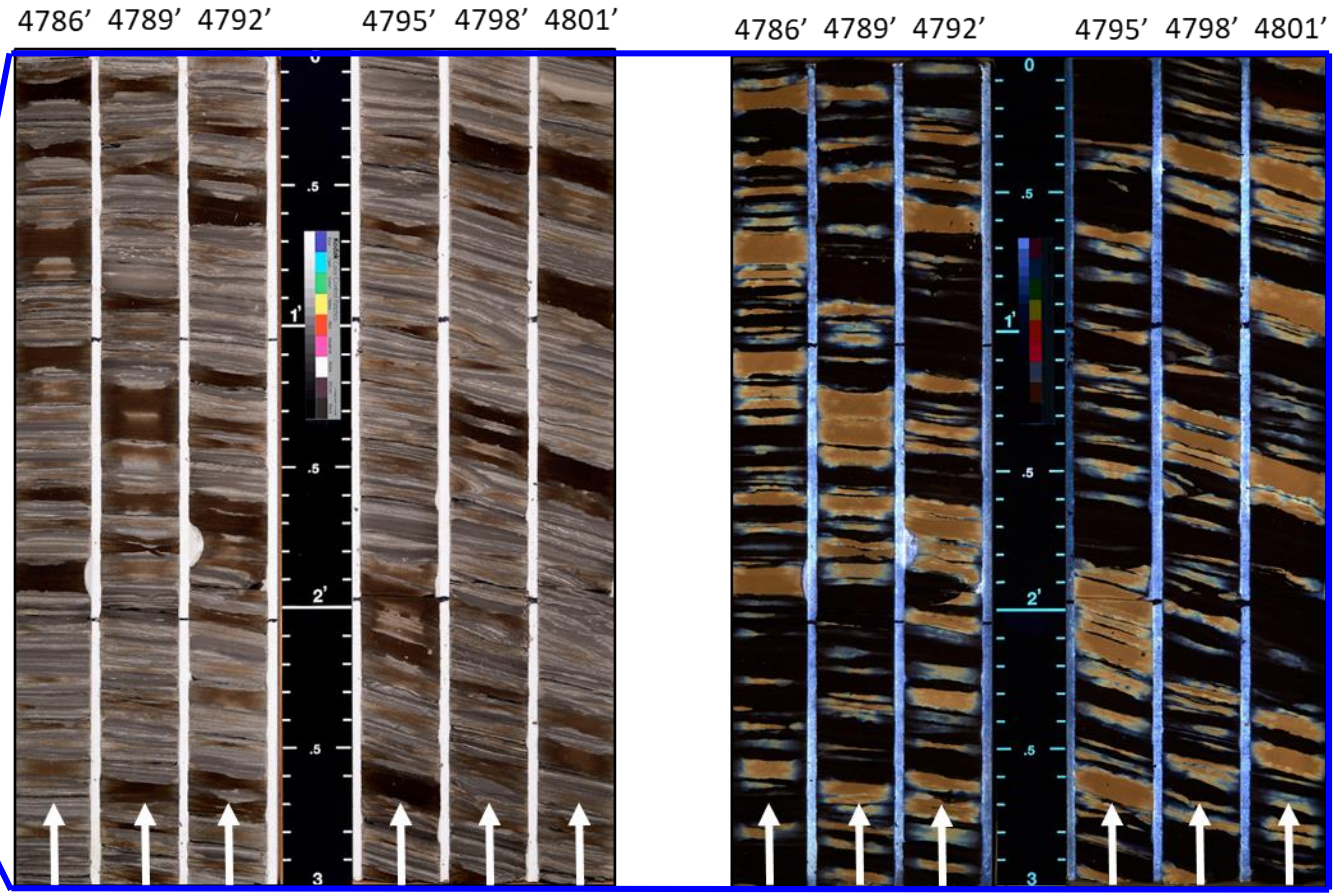
Oil-stained Nanushuk Reservoir



NMR log from the Horseshoe 1 (Discovery well)

Integration of advanced Nuclear Magnetic Resonance log and core

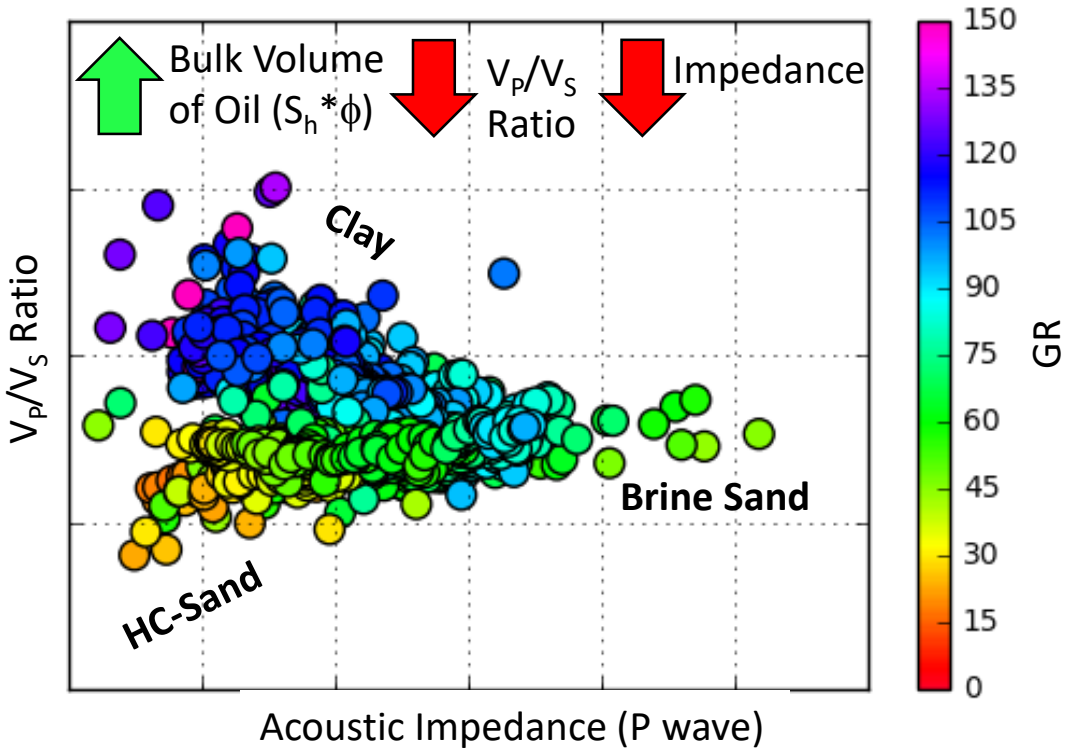


Core under regular light

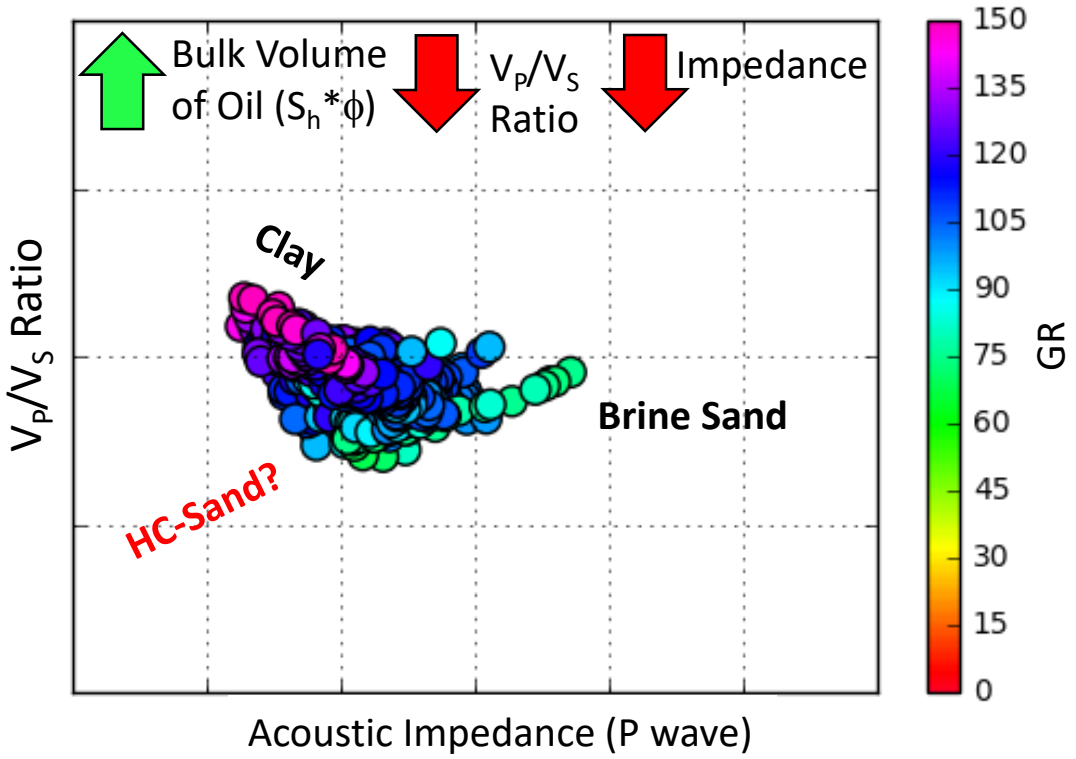
Core under UV light

Rock Physics: Nanushuk Wet vs. Dry Wells

Wells with hydrocarbon shows



Dry wells



High oil-saturated sandstone can be observed based on certain V_P/V_S ratio, acoustic impedance, and gamma-ray cutoffs. This information can be used in log-to-seismic transform and seismic inversion to map potential HC-zones. A lot of work on this topic is in progress now.

After Bhattacharya and Verma, 2019

Summary

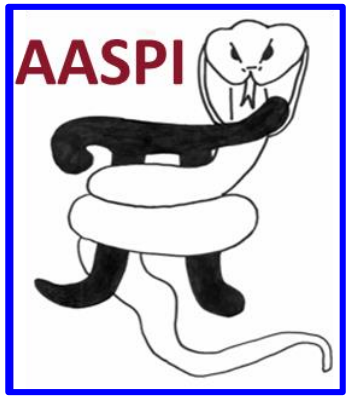
- The Nanushuk-Torok sequence reveals a prograding shelf-edge system at a mega-regional scale.
- Coherent energy, Sobel-filter similarity, and spectral decomposition attributes illuminated shelf-edges, slides, channels, MTDs, and basin-floor fans, etc.
- Low-resistivity, laminated sand-shale reservoir
- Core and log-based rock physics relations are used to predict the sweetspots at a regional scale via seismic inversion.
- Future studies include more work on the convergence attribute, 5D interpolation, and machine learning-assisted facies mapping.

Lithology + Porosity + Oil

Features/Properties	Values/Description
Depth (Measured Depth)	500-6,000 ft
Dominant Lithology	Sandstone
Porosity	13-30%
Permeability	> 10-100 mD
Prospects	Shelf-edges (lateral extent of 10s-100s of miles), channels, and basin-floor fan, etc.
Proven Discoveries	Yes

Acknowledgements

- Thanks to the Alaska Department of Natural Resources, Division of Oil and Gas for making the tax-credit 3D seismic data available http://dog.dnr.alaska.gov/Information/GeologicalAndGeophysicalData.
- AASPI software was used to compute seismic attributes.
- Petrel (Schlumberger) was used for seismic interpretation.
- Powerlog (CGG) was used for petrophysical analysis.



Schlumberger

CGG

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