Seismic Attribute and Petrophysical Studies on the Nanushuk and Torok Formations on the North Slope, AK

Shuvajit Bhattacharya, *University of Alaska Anchorage and*
Sumit Verma, *University of Texas Permian Basin*

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1. SUMMARY

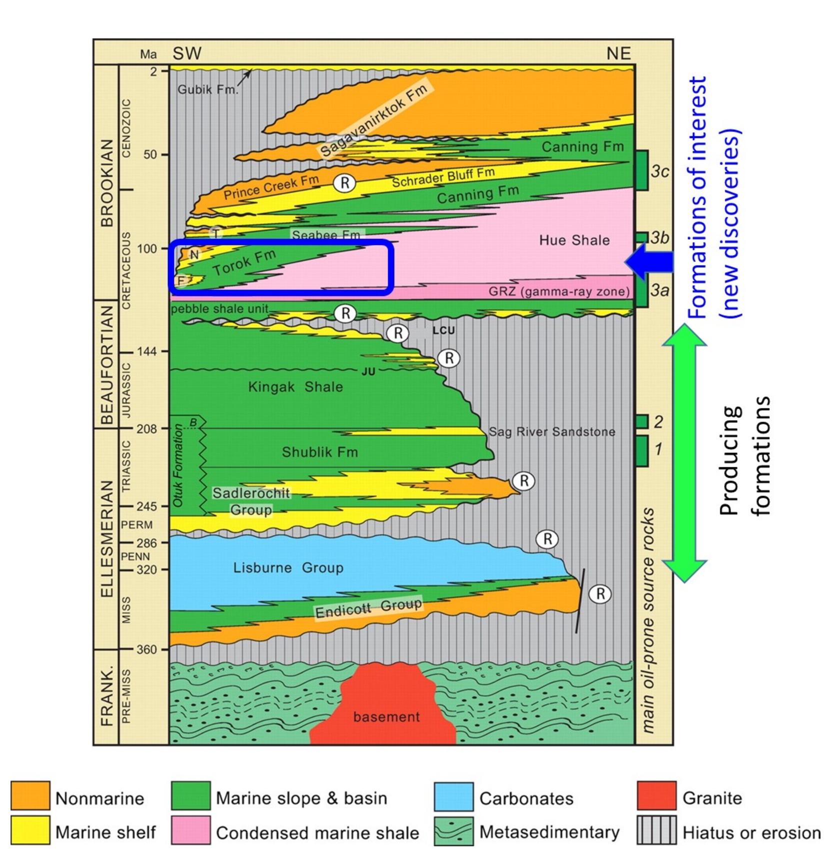
Exploration of the Brookian reservoirs in the Nanushuk and Torok formations on the North Slope of Alaska is a hot topic and presents opportunities to the oil and gas community because of their shallow depth, vast extent, and scope of development, etc. The consecutive hydrocarbon discoveries announced by Repsol-Armstrong, Caelus Energy, and ConocoPhillips in 2015, 2016, and 2017 have indicated the presence of the vast recoverable resources on the North Slope in the Nanushuk and Torok formations.

The goal of this work is to detect the dominant geologic features in the these formations using a combination of seismic attributes at the regional scale and analyze critical petrophysical and rock physics properties to evaluate formation heterogeneities and identify the reservoir targets by integrating well-log and core data at the well-scale.

The Nanushuk Formation is expressed as topset reflections, whereas the Torok and Gamma-Ray Zone (GRZ) formations are expressed as foresets and bottomsets on the seismic reflection data. Seismic-attribute-assisted mapping revealed the presence of different geomorphological features, including shelf-edges, channels, slides, and basin floor fans, all with significant amplitude anomalies. The shelf-edges continue for 10s-100s of miles along N/NW and EW directions, depending on the areas.

The internal characters of these formations delineated by conventional well-logs and advanced petrophysical analysis reveal their vertical heterogeneities and complexities, in terms of reservoir properties. The reservoirs are both vertically and laterally heterogeneous. These are mostly low-resistivity pay. Only a few zones in the parasequences are oil-saturated. A combination of low V_P/V_S ratio and low acoustic impedance proved to be a useful proxy to detect the hydrocarbon-bearing sand intervals in these formations.

2. GEOLOGY OF THE STUDY AREA



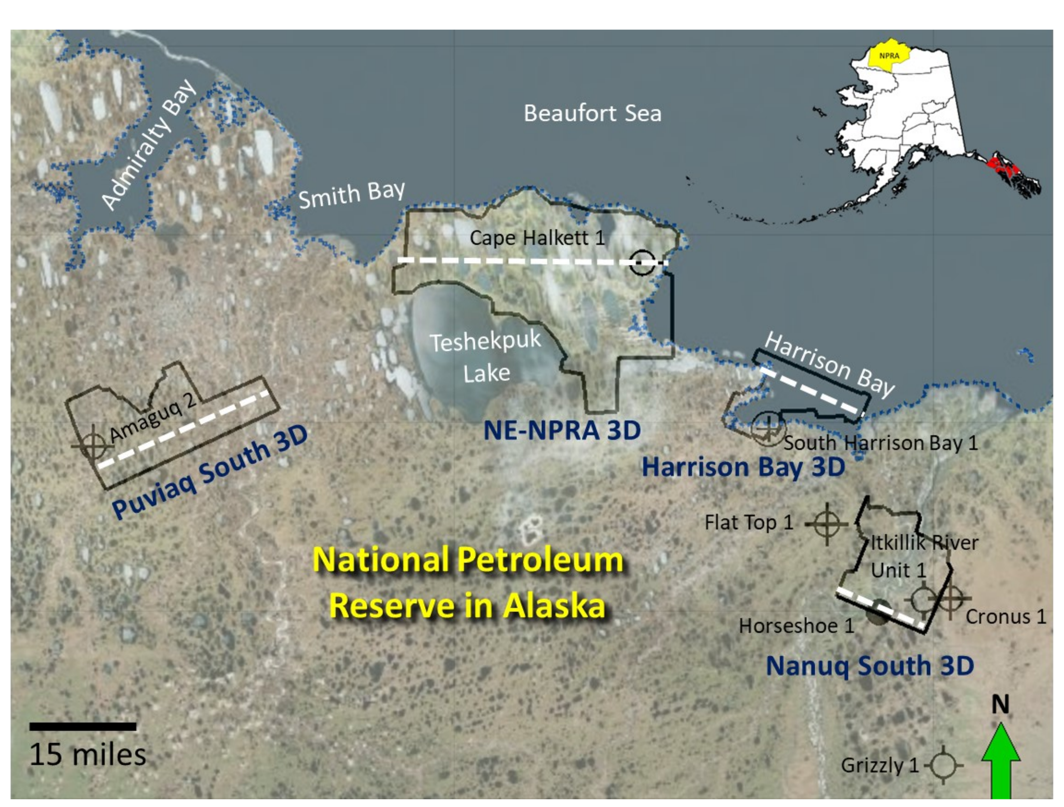


Figure 1. In left: Generalized chrono-stratigraphic column on the North Slope (Bird and Houseknecht, after, 2011). Prominent hydrocarbon reservoirs are indicated by R. For details, please see Houseknecht, 2019b and (Bird and Houseknecht, after, 2011. The focus of this study is on the Brookian Nanushuk (marked by N) and Torok formations.

In right: The study area in the NPRA, Alaska (with 3D seismic surveys and wells). Three large 3D seismic surveys (Nanuq South, Harrison Bay, NE-NPRA, and Puviaq South 3D) along with a few wells with conventional and advanced petrophysical logs and core samples are available for this study.

3. SEISMIC ATTRIBUTE ANALYSIS

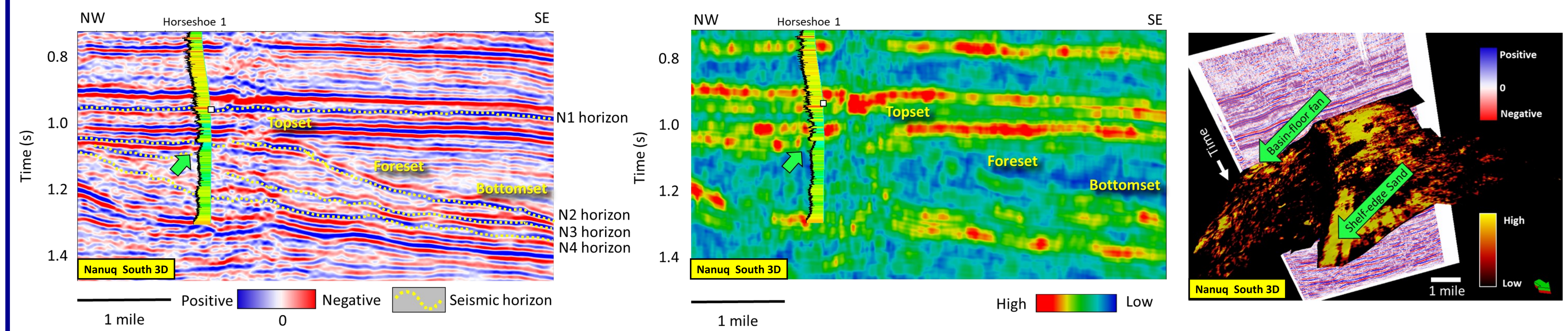


Figure 2: A seismic amplitude section along NW-SE (a) and corresponding amplitude anomalies using RMS attribute (b), with the Horseshoe 1 well being displayed. in the Nanuq South 3D seismic survey area. The gamma log in the Horseshoe 1 well shows the characteristic coarsening-upward sequences. The green arrow indicates the zone from hydrocarbons were discovered. Figure 2b shows the low-angle clinoforms with significant amplitude anomalies in the topsets, shelf-edges, and foresets. The Horseshoe 1 well was used for well-seismic tie. The white filled rectangle shows the top of the Nanushuk Formation in the well, which matches with the seismic reflector signatures. (c) Coherent energy attribute extracted from the N2 clinoform in the Nanuq South 3D survey, shows different types of geologic features (shelf-edges, beach ridges, and basin-floor fans) in the area.

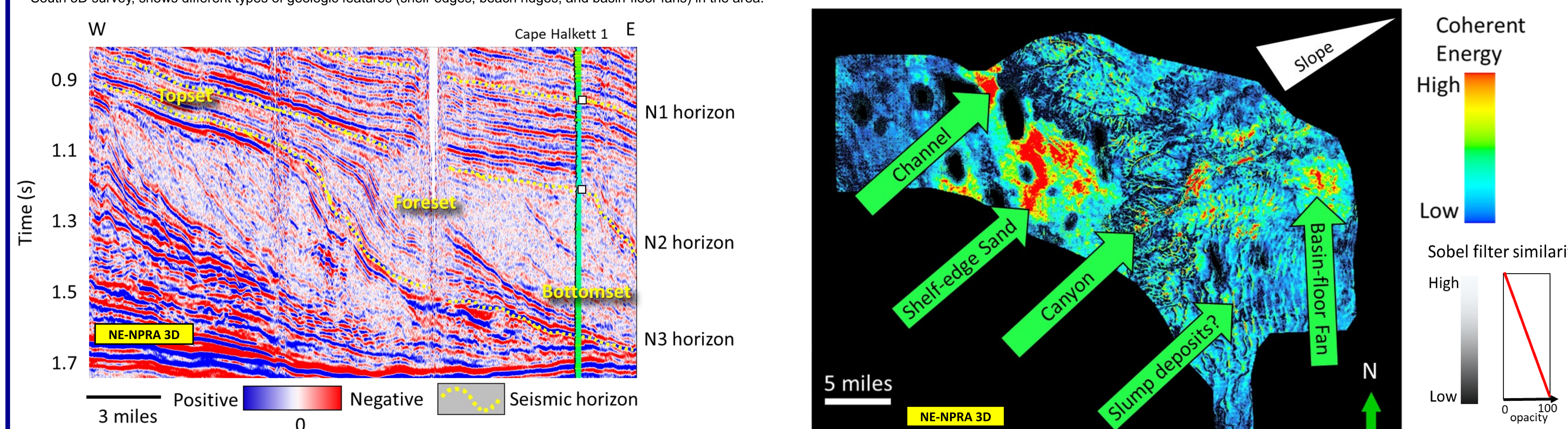


Figure 3: (a) A seismic amplitude section along W-E in NE NPRA 3D survey. Figure shows the clinoforms with significant amplitude anomalies in the topsets, shelf-edges and foresets. The clinoforms observed in this area are large in dimensions. The Cape Halkett 1 well was used for well-seismic tie. (b) Corendered seismic attributes (coherent energy and Sobel-filter similarity) on a clinoform surface in plan view in the NE-NPRA 3D survey area. Several geologic features such as shelf-edges, low-sinuosity channels, deep canyons, slump scars, and basin-floor fans can be identified and mapped using such combined attributes.

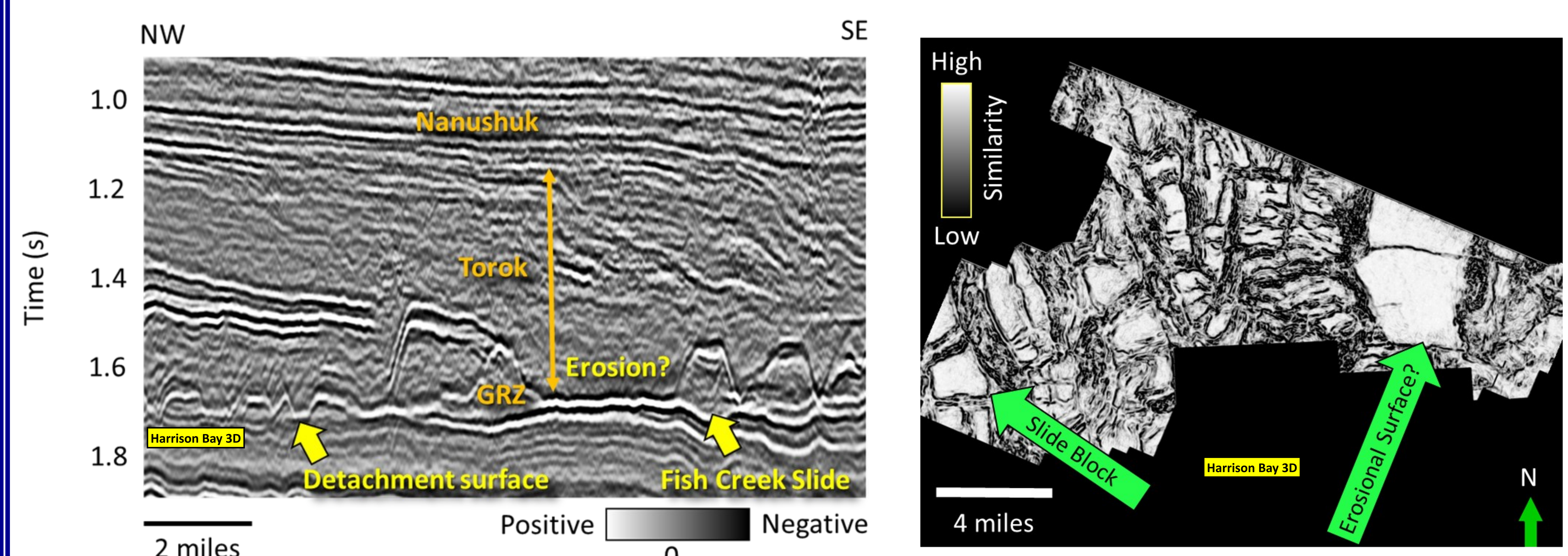


Figure 4: (a) A seismic amplitude section along NW-SE. (b) Coherence Time slice around 1.7 seconds. Large slides (e.g., Fish Creek Slide) were interpreted on the seismic sections, mostly affecting the Torok Formation. The presence of the low-velocity, organic-rich GRZ shale generates velocity push-down effect at several places. Productive wells were drilled in the Jurassic and Cretaceous intervals, below slides.

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3. SEISMIC ATTRIBUTE ANALYSIS continued..

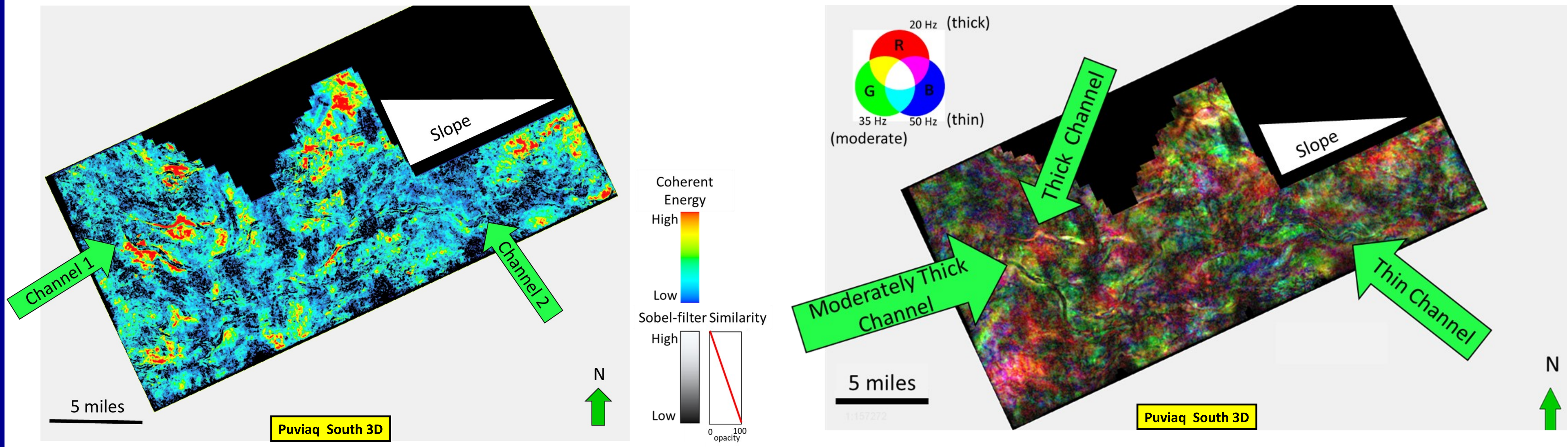

Figure 5: (a) Co-rendered coherent energy and Sobel-filter similarity attributes (a), and spectral decomposition (b) attributes along a time slice (1152ms) in the Puviaq South survey, showing the presence of channels with variations in amplitude anomalies and thickness. The slope direction is toward the northeast (marked by a white triangle). Notice that the rainbow color (with no black color) scale of coherent energy allows its effective co-rendering with Sobel filter similarity (black-gray-white scale). We used the RGB color scheme, corresponding to three different frequencies, 20 Hz (red), 35 Hz (green), and 50 Hz (blue), to illustrate the variations in the thickness of the channels.

5. Rock Physics

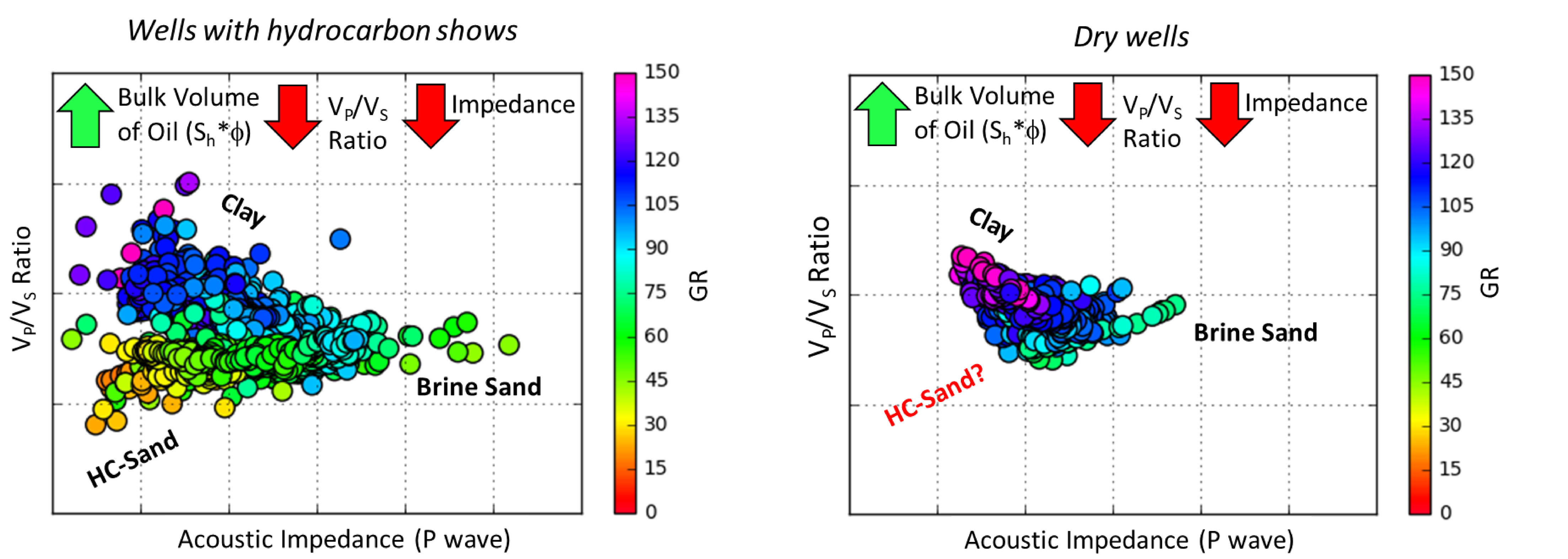

Figure 8: Rock physics cross-plot showing the relation between V_P/V_S ratio and P-wave acoustic impedance, color-coded by GR log in a few wells with hydrocarbon shows (a) and no shows (dry) (b). With such plots, oil-bearing sand zones can be distinguished from brine-sand and clay zones. The presence of hydrocarbons in the reservoir decreases the V_P/V_S ratio. Research on this topic is in progress.

6. CONCLUSIONS

- 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. features
- 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 work includes: the convergence attribute, 5D interpolation, and machine learning-based facies mapping.

8. ACKNOWLEDGEMENTS

We thank the Alaska Department of Natural Resources, Division of Oil and Gas for making the tax-credit 3D seismic data available. AASPI software was used to compute seismic attributes. Petrel™ (Schlumberger) was used for seismic interpretation. Powerlog™ (CGG) was used for petrophysical analysis. For questions, please email **sbhattacharya3@alaska.edu** or **verma_s@utpb.edu.**

4. PETROPHYSICAL ANALYSIS

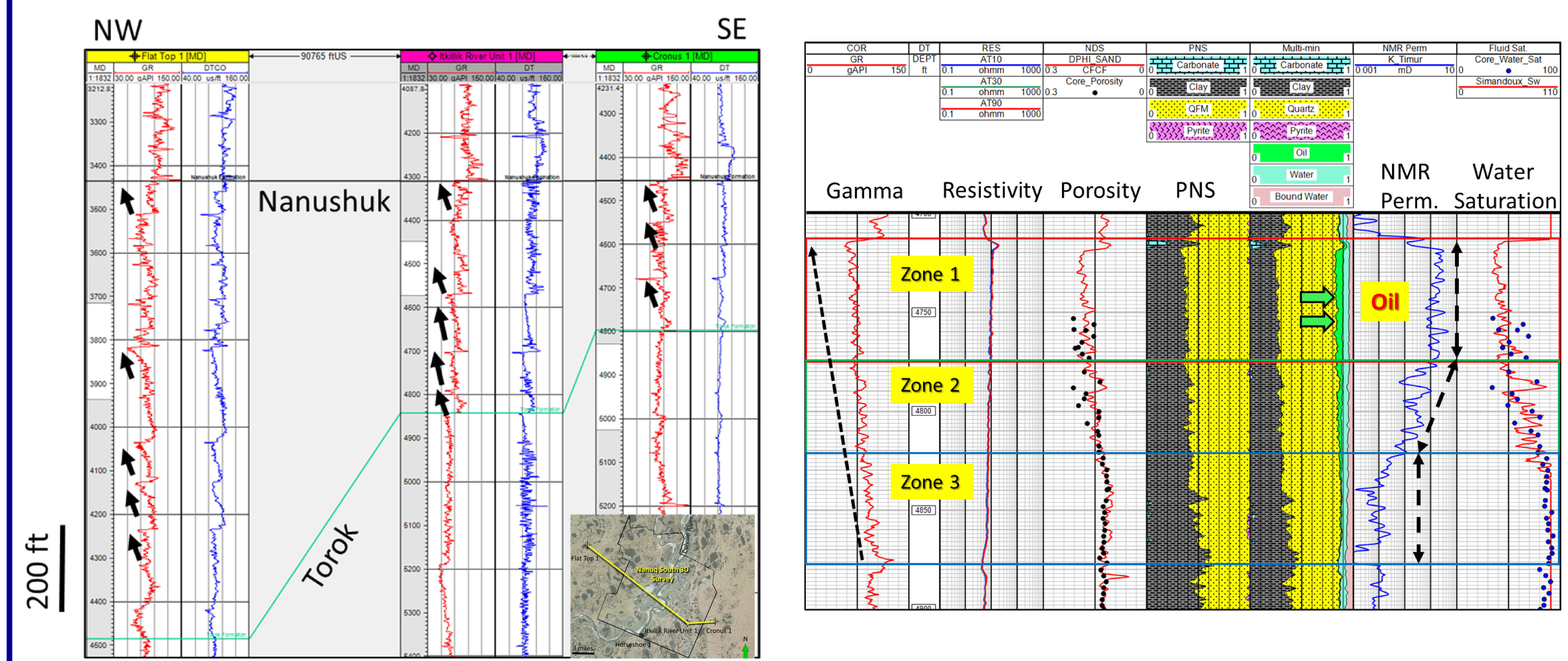

Figure 6: (a) A well-log cross-section in the Nanuq South survey area. GR log (red color) is shown in the 1st track followed by the sonic log (blue color) in the 2nd track. The GR and sonic responses indicate the presence of multiple coarsening upward sandstone packages (marked by black arrows) which thin toward the basin along E/SE. The yellow line on the index map shows the well-log cross-section. (b) Conventional and advanced petrophysical logs along with multi-min model for the oil-stained zone in the Nanushuk Formation in the Horseshoe 1 well. The first, second, and third tracks show the conventional triple-combo logs, whereas the tracks 4, 5, 6, and 7 show the advanced petrophysical logs (PNS, petrophysical inversion model, NMR-based permeability, and NMR bin porosities). The black arrow shows the coarsening upward sequence in the gamma-ray log, which is indicative of sand. The petrophysical model coupled with NMR-based permeability and bin porosity curves shows the presence of oil near the top of the parasequence and the reservoir heterogeneity. Higher T2 (NMR relaxation time)-based bin porosity values in track 7 are indicative of hydrocarbon.

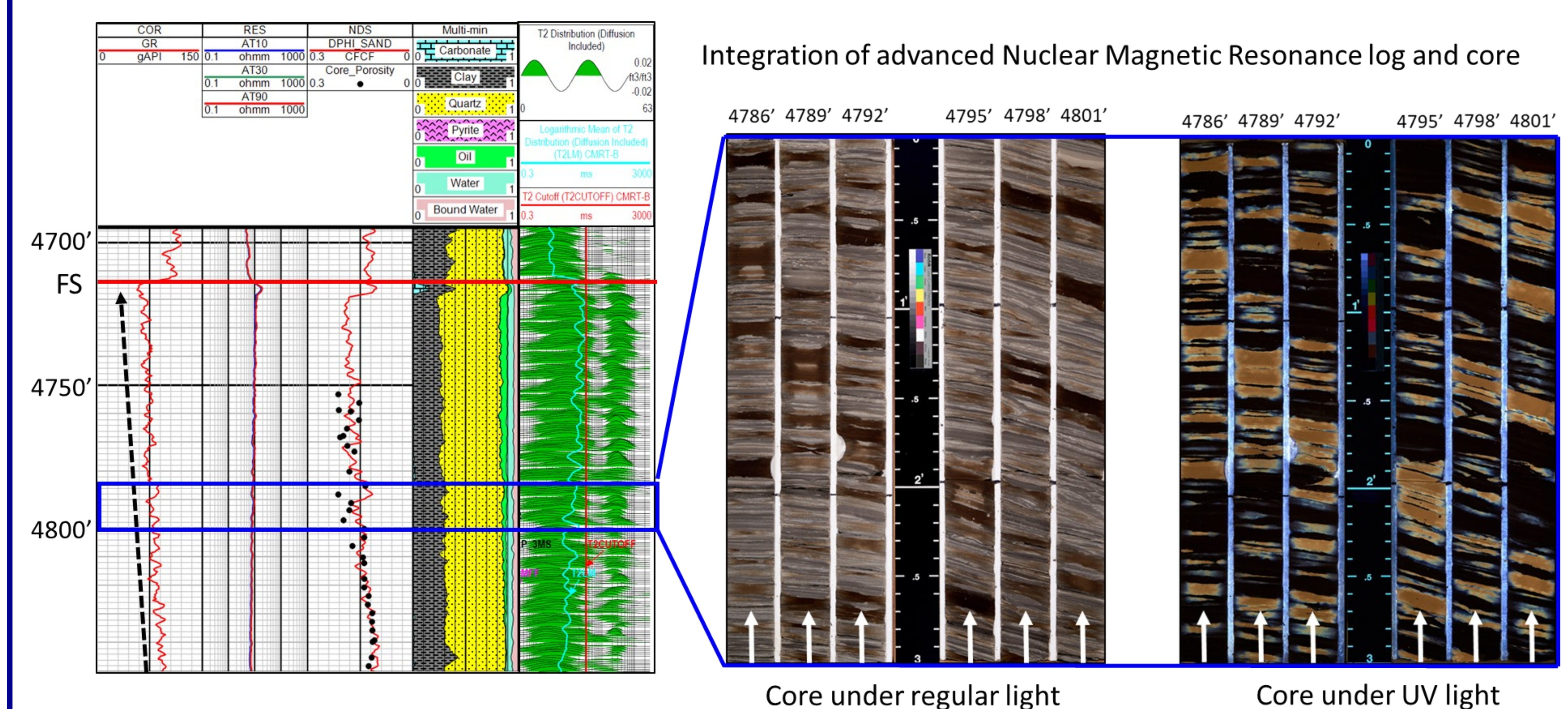

Figure 7: NMR log from the Horseshoe 1 well showing the T2, relaxation-time based bin porosity (track 5). Higher T2 values in track 5 are indicative of hydrocarbons. The bimodal amplitude distribution shows the evidence of hydrocarbons (on the right side of the vertical bidirectional red arrow), which can be validated with the available core photograph in the 4,786-4,792 feet interval (marked by a black rectangle in the NMR log tracks) in the right showing the oil-stained Nanushuk reservoir.

7. REFERENCES

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