GC A Tale of Two Conventional Reservoirs: Nanushuk and Torok on the North Slope, Alaska*

Sumit Verma[1] and Shuvajit Bhattacharya[2]

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[1]University of Texas Permian Basin, Odessa, Texas (verma_s@utpb.edu)
[2]University of Alaska Anchorage, Anchorage, Alaska

General Statement

Exploration of the Brookian-age Nanushuk and Torok formations on the North Slope of Alaska is a hot topic these days. The Nanushuk and Torok formations are Cretaceous progradational clastic deposits in the Colville Basin of Alaska. These formations offer new opportunities to the oil and gas community because of their shallow depth, vast spatial extent, publicly available data, scope of development and other appealing features.

Companies like Repsol-Armstrong and ConocoPhillips announced and proved hydrocarbon discoveries in these formations in the Pikka-Horseshoe and Willow fields in 2015 and 2017 (Figure 1). Caelus Energy announced another discovery in the Torok Formation in the Smith Bay area in 2016. A recent study by U.S. Geological Survey in 2017 has estimated that there are at least 8.7 billion barrels of oil and 25 trillion cubic feet of natural gas reserves in these formations. These discoveries have attracted several explorers on the North Slope, including Oil Search, 88 Energy, XCD Energy, Pantheon Resources, and Malamute Energy, among others. As the number of exploration and appraisal wells increased, so did the varieties of the results. Among the wells drilled in 2019-20, some showed promising results (such as the Stirrup 1, Mitquq 1, and Tinmiaq wells), whereas others showed mixed results (such as the Charlie 1, and Winx 1), in terms of moveable hydrocarbons. Tinmiaq wells are inside the Willow Field. As per the publicly available information, the Stirrup 1 and Mitquq ST1 wells flowed oil at 3,520 bopd and 1,730 bopd, respectively. It is also interesting to note that some of the not-so-successful wells, such as the Winx 1, are within a few miles of the discovery wells, such as the Horseshoe 1. Therefore, it is apparent that the oil reservoirs are present in some places, not everywhere. Identification, appraisal and exploitation of these reservoirs require a multifaceted and multiscale approach. These reservoirs pose both opportunities and challenges to the geoscientists and engineers.

Reservoir Characteristics

By integrating eight 3-D seismic surveys, well logs, and core (poro-perm and special core scan) data, we can discuss the characterization of the Nanushuk and Torok formations. The 3-D seismic surveys cover an area of about 2,389.21 square miles (6,188 square kilometers) and have been publicly released through a tax-credit program (AS 43.55 Exploration Tax Credit Project) by the Department of Natural Resources, state of Alaska.

The Nanushuk Formation is a clastic fluvial-deltaic-shelf succession, whereas the Torok Formation is its basinward equivalent. These formations are primarily composed of sand and shale sequences. Seismic data show the presence of low-angle clinothems all over the study area, where the Nanushuk Formation is expressed as topset, and the Torok Formation is expressed as foreset and bottomset (Figure 2). Seismic-attribute-assisted mapping reveals the presence of prograding shelf edges, channels, and basin-floor fans, all with significant amplitude anomalies, which could be potential reservoirs (Figure 2). Apart from these deposits, we also observe mass-transport deposits and sediment wave deposits. Co-rendering of seismic attributes, such as coherent energy, reflector convergence, Sobel-filter similarity (coherence) and spectral decomposition reveals these geomorphological features in more detail.

Both Nanushuk and Torok formations are internally heterogeneous, as revealed by petrophysical data. Petrophysical models show that only a few zones in the parasequences are oil-saturated (Figure 3). Based on the core data, the porosity and permeability in these formations range from 5 percent to 35 percent and approximately 0.001 to 1,000 millidarcies, respectively. In general, the Torok Formation is tighter than the Nanushuk Formation. Burial depth affects reservoir porosity and permeability. The effect is more in the south (near the Brooks Range) than the north.

The ratio of P-wave and S-wave velocity (VP/VS) is a good indicator of hydrocarbon-bearing sandstones in these formations (Figure 4). The wells with hydrocarbon-shows have a relatively lower VP/VS ratio (generally less than 2.0) than the wells without shows. This indirect technique can be used to guide seismic impedance inversion for mapping the hydrocarbon-bearing intervals. The VP/VS ratio varies across the study area, as it depends on burial depth and porosity. In addition, these formations also contain micro-fractures at places. Micro-CT (“computed tomography”) scan results show the variations in pore size, fractures, lithic grains and anisotropy in these formations, which are useful to understand the reservoir compartmentalization and effective porosity (Figure 5).

Challenges

Although the Nanushuk and Torok formations present significant opportunities, there are several challenges. The presence of ice lakes and permafrost deteriorates the seismic imaging quality and affects proper depth positioning of the wells. Identification of subtle stratigraphic features, such as shelf edges with amplitude anomalies touted as major features holding hydrocarbons, gets complicated due to the presence of these features. New geophysical data acquisition and processing techniques are needed before applying conventional interpretation techniques.

These formations are composed of laminated sand-shale sequences and contain thin-bedded reservoirs, which pose challenges to geophysicists and petrophysicists. First, thin beds create seismic amplitude anomalies, which may look very similar to direct hydrocarbon indicators, commonly known as DHI. A few wells, which look significantly good on seismic amplitude anomalies (i.e., RMS amplitude) in these formations, have turned out to be uneconomical or even resulted in dry holes. In addition, these reservoirs typically show Class 1 or 2 amplitude variations with offset response. Therefore, we recommend analyzing pre-stack and angle-stack seismic data, rather than commonly used post-stack seismic data. Second, traditional Archie-based fluid saturation estimates are not applicable to thin-bedded reservoirs. In general, these reservoirs are low-resistivity pay, where the resistivity is suppressed due to high clay content. The clay content in the reservoirs can reach up to 50-60 percent at places. In addition, the distribution pattern of clay (laminar versus structural versus dispersed) is an important factor in reservoir deliverability. There is evidence of the dispersed clay in Nanushuk Formation. Lab-based studies are required for better calibration and validation purposes.

Conclusions

Although there have been some studies on the distribution of the source rocks and conceptual modeling of fluid migration in Alaska, a data-driven basin-wide petroleum system model has not been published yet. In addition to light oil, we expect a few areas containing heavy oil and condensate gas deposits, some of which have been confirmed by the recent drilling activities.

Drilling on the North Slope is expensive (in the order of tens of millions of dollars) due to remote locations, logistics, limited drilling season and important environmental regulations. Therefore, it is vital to invest in the science of these reservoirs prior to drilling and completion. For further reading, please see Bhattacharya and Verma, 2020.

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Bhattacharya, S., and S. Verma, 2020, Seismic attribute and petrophysics-assisted interpretation of the Nanushuk and Torok formations on the North Slope, Alaska: Interpretation, v. 8, p. 1-18.

For tax-credit seismic data, please see: (websites accessed July 11, 2020)

dggs.alaska.gov/gmc/seismic-well-data.php

dog.dnr.alaska.gov/Information/GeologicalAndGeophysicalData

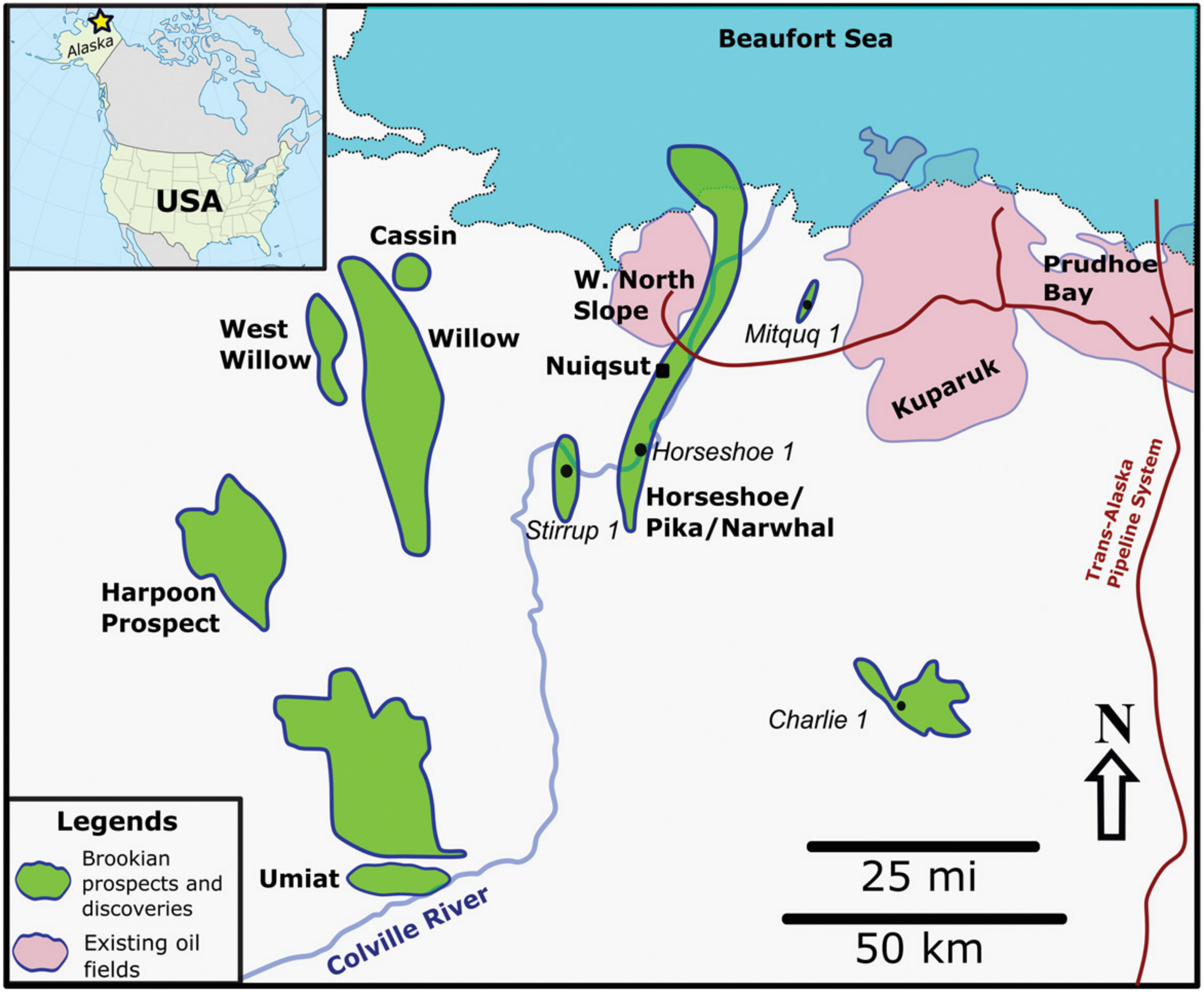

Figure 1. The study area on the North Slope, Alaska, showing some of the major prospects and discoveries (in light green) and producing areas (in light red). The data is gathered from publicly available information.

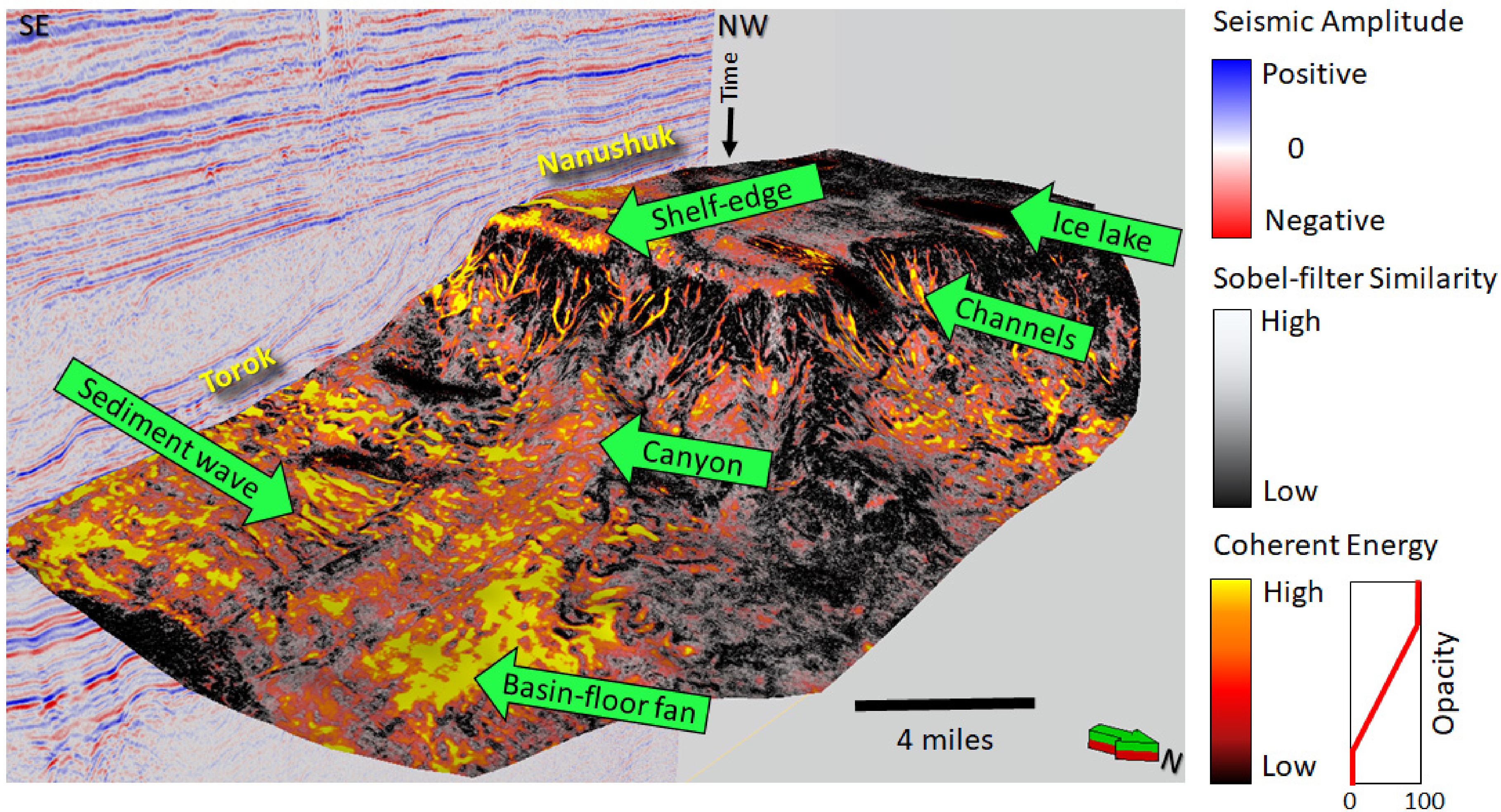

Figure 2. A northwest-southeast oriented seismic section (vertical exaggeration ~50x) with Sobel-filter similarity co-rendered with coherent energy attribute extracted from a clinoform surface in a 3-D survey near the Smith Bay. The attribute map shows different types of geologic features (shelf edges, canyons, basin-floor fans, and sediment wave deposits) in the area. The dark black color on the surface (near the shelf edge) indicates an ice lake. Data courtesy of the Alaska Department of Natural Resources.

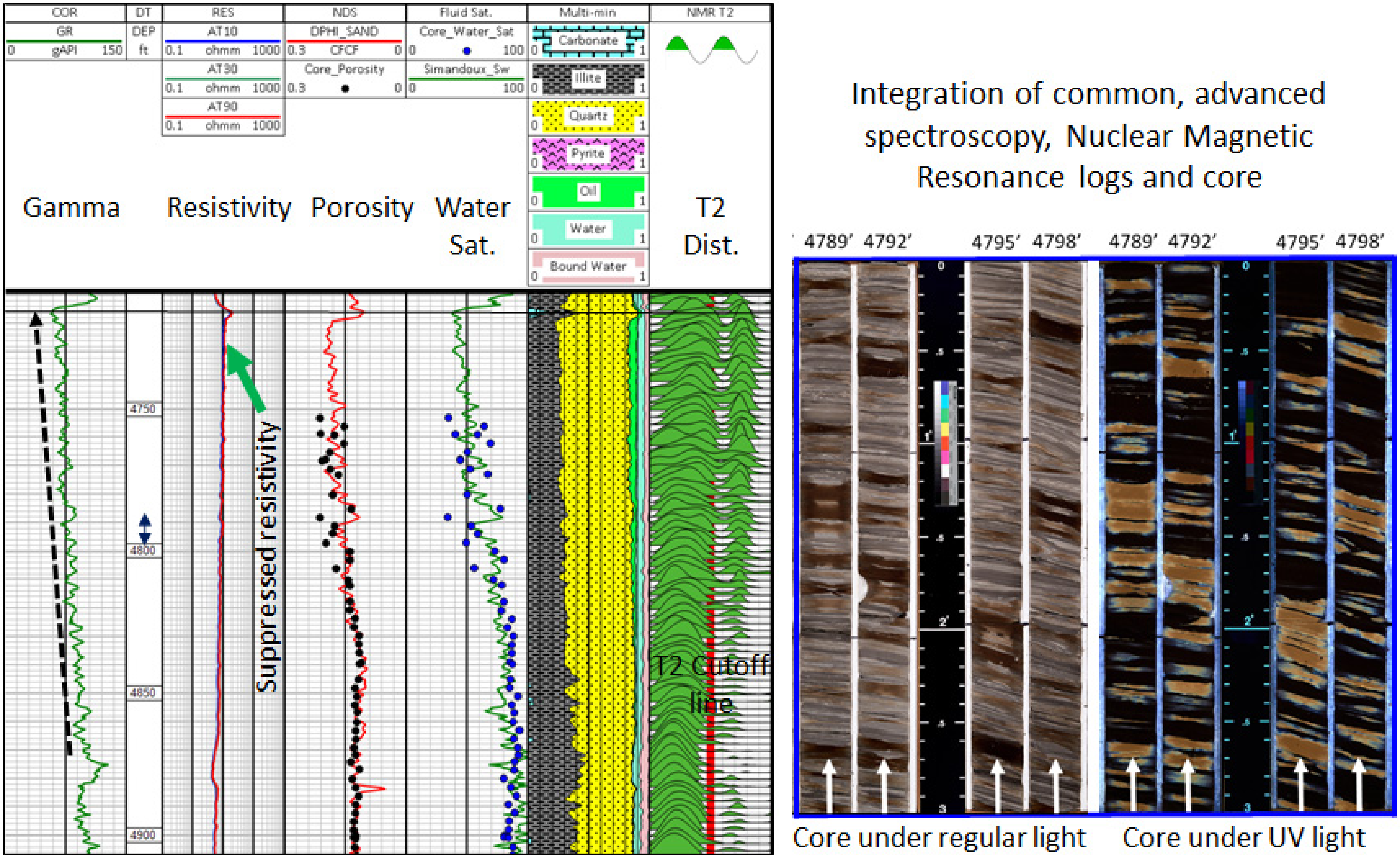

Figure 3. A well log display from the discovery zone in the Nanushuk Formation in the Horseshoe 1 well, showing common, advanced well logs, core data, and core photographs. The bimodal T2 distribution in the NMR log (track 6) is indicative of hydrocarbons. The double-headed arrow in the depth track shows the core photographs in the right. The photograph illustrates the oil-stained Nanushuk reservoir under regular and ultraviolet light. It is a thin-bedded, low-resistivity reservoir. Data courtesy of the Alaska Oil and Gas Conservation Commission.

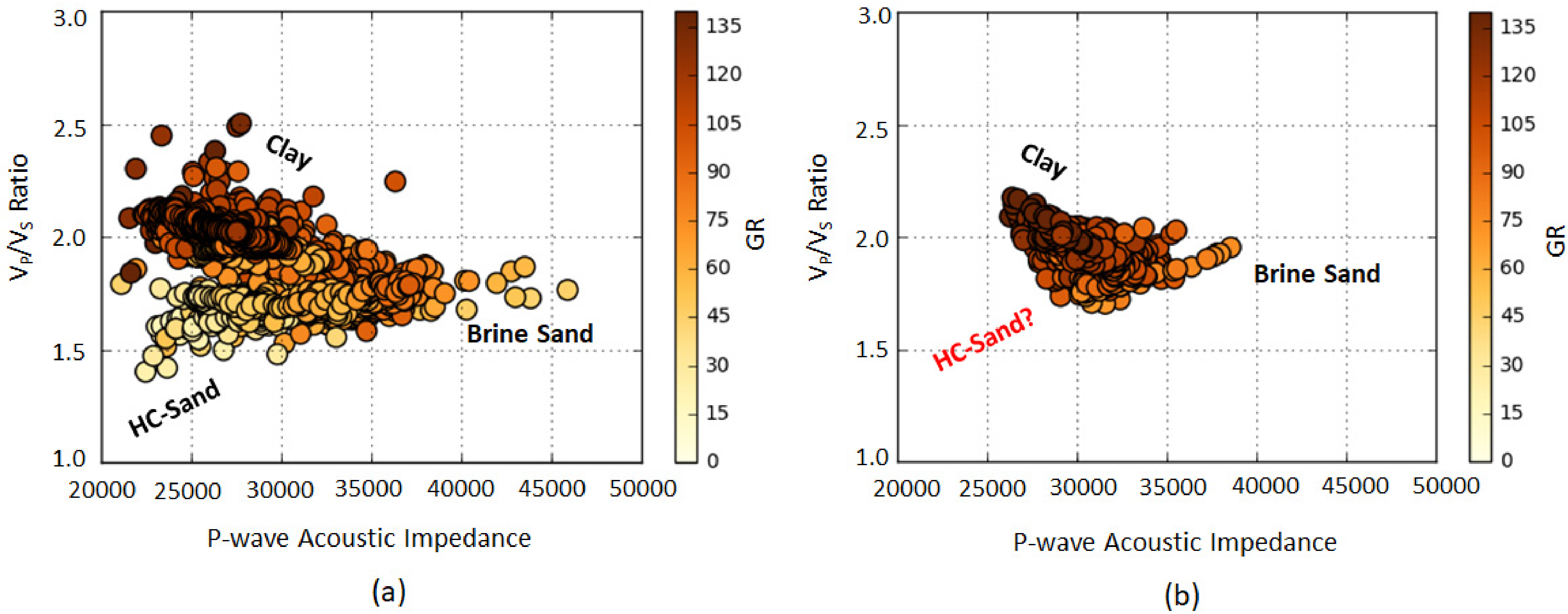

Figure 4. Rock physics relation between V_P/V_S ratio and P-wave acoustic impedance, color-coded by GR log in wells with (a) hydrocarbon shows, and (b) no shows (dry). The wells with hydrocarbon shows in the Nanushuk sandstones have low V_P/V_S ratio and low acoustic impedance.

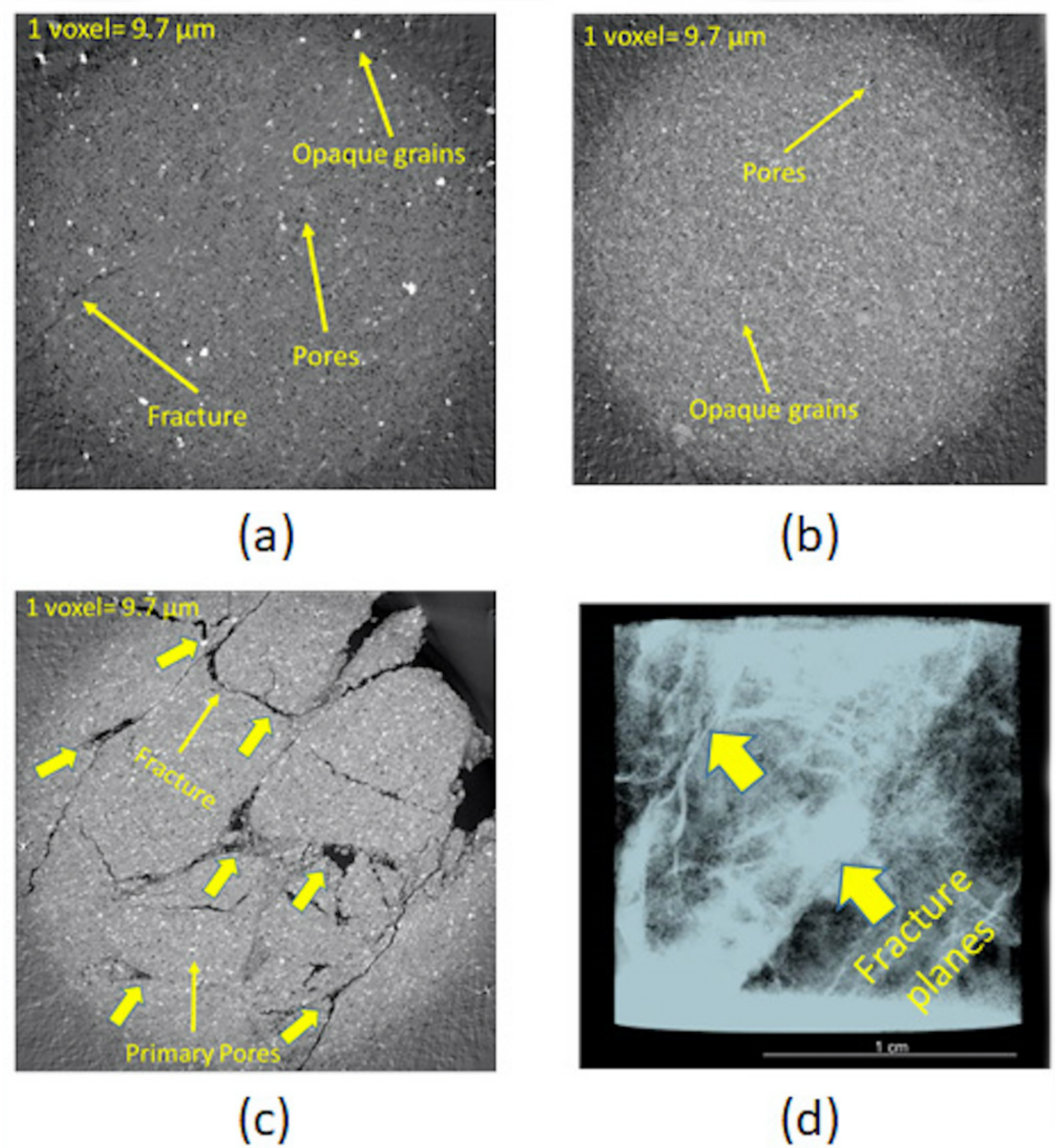

Figure 5. Micro-CT scan results showing the pore and fracture distribution in the Nanushuk and Torok formations, with hydrocarbon shows (a, c, and d) and without hydrocarbon shows (b). Some of the hydrocarbon-show wells have both intergranular pores and fractures.