Nanushuk Formation Discoveries: World-class exploration potential in a newly proven stratigraphic play, Alaska North Slope

2018 AAPG ACE Discovery Thinking Forum

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Nanushuk and Torok Formations, Slope Mountain
Topics & Themes

- North Slope introduction and recent activity
- Regional geology – Nanushuk & Torok Fm plays
- Compare & contrast recent major discoveries
- Basal Nanushuk topset play – seismic expression
- Cracking the nut – significance of the new play
- Implications for undiscovered oil

Nanushuk Formation, Killik Bend, Colville River
Winter-only Remote Exploration - Ice Roads, Ice Pads -
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-Horseshoe and Willow trends.
North Slope Petroleum Systems - Focus on Lower Brookian Sequence -

Modified after Bird and Houseknecht, 2002 and Houseknecht, 2003
**North Slope Tectonic Setting - Nanushuk and Torok Discoveries**

- Major sequences
- Foothills to south
- Modern Barrow Arch
- Rifted margin
- Pikka-Horseshoe
- Willow
- Smith Bay

Interpreted seismic profiles courtesy of David Houseknecht, USGS (in BOEM Fact Sheet 2017-12b)
## Major Recent Brookian Discoveries

<table>
<thead>
<tr>
<th></th>
<th>Smith Bay</th>
<th>Willow</th>
<th>Pikka/Horseshoe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator(s)</td>
<td>Caelus</td>
<td>ConocoPhillips</td>
<td>Oil Search/ConocoPhillips</td>
</tr>
<tr>
<td>Reservoir Formation</td>
<td>Torok Fm</td>
<td>Nanushuk Fm</td>
<td>Nanushuk Fm</td>
</tr>
<tr>
<td>Penetrations to date</td>
<td>2</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Location</td>
<td>State Waters Offshore of NPRA</td>
<td>Federal Onshore Northeast NPRA</td>
<td>Onshore Colville Delta</td>
</tr>
<tr>
<td>Road/Pipeline Tie-in</td>
<td>~ 125 miles</td>
<td>~ 28 miles</td>
<td>~ 20 miles</td>
</tr>
<tr>
<td>Trap type</td>
<td>Turbidite Stratigraphic</td>
<td>Topset Stratigraphic</td>
<td>Topset Stratigraphic</td>
</tr>
<tr>
<td>Net Pay</td>
<td>183-223 ft</td>
<td>42-72 ft</td>
<td>&lt; 225 ft</td>
</tr>
<tr>
<td>Oil Gravity</td>
<td>40-45 degree API (calc)</td>
<td>44 degree API</td>
<td>30 degree API</td>
</tr>
<tr>
<td>Test Rate</td>
<td>No Flow Tests</td>
<td>&lt; 3,200 bopd vertical</td>
<td>~ 2,100 bopd vertical; 4,600 bopd horizontal</td>
</tr>
<tr>
<td>Contingent Recoverable Resource</td>
<td>1.8-2.4 BBO (est)</td>
<td>300 MMBO</td>
<td>1.2 BBO</td>
</tr>
<tr>
<td>Expected Production (Operator Releases)</td>
<td>&lt; 200,000 bopd</td>
<td>40,000-100,000 bopd</td>
<td>&lt; 120,000 bopd</td>
</tr>
</tbody>
</table>
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 strata near the shelf edge during falling stage or lowstand stage, and sealed by overlying mudstone deposited with next transgression.
Flattened on middle Schrader Bluff Formation

Nanushuk Fm
Topsets

Torok Fm
Slope foresets & Basin-floor bottomsets

Note distortion of Tuluvak growth-faulted interval caused by flattening on shallower horizon

MCS = mid-Campanian unconformity
• 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.
Conventional reservoirs;
Poroperm data cluster in geographically defined trends, which in turn relate to maximum burial and uplift.
Fish Creek slumps

Basal Nanushuk Seismic Anomalies - 1981 2D Data, Northeast NPRA -

Inigok 1  North Inigok 1  North Kalikpik 1

- Parentheses indicate interpreted horizons.

HRZ – Hue Shale (oil source rock)

Tuluvak & Seabee Fms

Nanushuk Fm

Torok Fm

Fish Creek slumps

Public seismic line USGS 81-27
BASAL NANUSHUK SHELF-MARGIN ANOMALIES
- 3D SEISMIC, NORTHERN NPRA -

Far offset stack reconnaissance

AVO Class volume characterization

Image courtesy L. Niglio and others, 2011 (BLM, BOEM) with permission of data owners WesternGeco, LLC and Geokinetics
Amplitudes corresponding to lowstand sands perched on incised outer shelf/upper slope

Image courtesy L. Niglio and others, 2011 (BLM, BOEM) with permission of data owners WesternGeco, LLC and Geokinetics
Busy targeting, drilling, and developing deeper discoveries;

Brookian Sequence is variable and confusing – geologists need regional stratigraphic context for correlating serendipitous sands, shows, etc.;

Nanushuk-Torok plays absent at the highly developed legacy fields to the east;

Expectation of biodegraded, viscous or heavy oil in shallow topsets, as above Prudhoe Bay, Kuparuk, & other fields, even locally in nearby NPRA;

Adjacent fields and prospects drilled from central pads, using deviated or horizontal trajectories, leaving upper stratigraphic units underexplored;

Many doubted existence of large topset strat traps, specifically ones that rely on updip pinch out in the proximal direction.
Willow discoveries announced January, 2017 (Tinmiaq 2 & 6) were a follow-up of this 2002 discovery. Play type is stratigraphically-trapped lowstand shoreface shelf-margin sandstones in lower Nanushuk Formation.

**Initial Willow Discovery - Nanushuk Fm**

**ConocoPhillips Hunter A**


Lower part of Nanushuk Fm
*(basal topset facies)*

Willow interval: secondary objective with light oil/gas shows; Tinmiaq 2 and 6 wells confirmed discovery, testing at up to 3,200 bopd

Top Torok Fm
*(uppermost slope facies)*

Sealing transgressive shale

Lowstand shoreface/shelf margin sandstones
Hunter A well drilled in NPRA in 2002 penetrated but didn’t fully evaluate an amplitude anomaly (Willow) noted at the bottom of the Nanushuk topsets. Not the primary or secondary objective, but provided key encouragement:

✓ Shoreface sands + Oil Shows + Seismic Amplitude = Viable Strat Trap Play!

- ConocoPhillips bid and won leases in 2002 NPRA lease sale on Nanushuk topset prospects supported by Hunter A results;
- Repsol/Armstrong drilled the Pikka discovery well Qugruk 3 in 2013 to a deeper Jurassic objective, discovered ~200’ pay in Nanushuk lowstand shelf margin sands as well as in Jurassic;
- Qugruk 8 and Qugruk 301 wells drilled in 2015 found and tested oil in same Nanushuk shelf-edge reservoir; announced discovery with very good flow rates;
- ConocoPhillips drilled Tinmiaq 2 and Tinmiaq 6 wells in 2016, targeting northern continuation of Willow trend discovered at Hunter A; announced Willow as major discovery in 2017.
- Armstrong/Repsol drilled Horseshoe 1, 1A discoveries in 2017, extending the Pikka trend some 20 miles to the south;
- ConocoPhillips conduct 7-well exploration/appraisal campaign in both Pikka-Horseshoe and Willow trends this winter.

The Events Unfold
- Discovery Timeline

- Hunter A well
  - Proof-of-concept
- Pikka Q8, 301
  - Flow tests
- Tinmiaq
  - Discoveries
- Horseshoe
  - Discoveries
- 7-well campaign

Pikka Discovery Typelog - Nanushuk Fm

Repsol Qugruk 3
P&A 4/1/2013

Sealing transgressive shale

Nanushuk Fm
(seismic topset facies)
upper facies tested 4,600 bopd in horizontal Q8 offset well

Top Torok Fm
(sandy lowstand wedge, seismic upper slope facies)

Known pay,
30 deg API on MDT

Potential pay

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.
Oil gradient 0.374 psi/ft

Gas-oil contact from logs @ -3990’

Water gradient 0.44 psi/ft

Nan 4 water point
Horseshoe 1

Oil-water contact from pressure data

Pressure continuity, > 600 ft oil column

Source: Oil Search Alaska Investor Seminar, December 2017
Pikka Nan 3 Reservoir
- Dip-oriented Nanushuk & Torok Cross Section -

Adapted from Oil Search acquisition presentation, November 2017
2018 Putu 2 & 2A Wells
- Delineating the Pikka-Horseshoe Trend, Nanuq South 3D -

Top Nanushuk

Nan 3
Nan 2
Nan 1
Nan 0

Putu 2 & 2A
TD?
TD?

Tofkat 1B, 1, 1A

B

J Chmielowski,
Alaska Division of Oil and Gas
2018 Stony Hill 1 Well - Redesigned for Nanushuk and Deeper Targets -

Stony Hill 1

Itkillik River Unit 1

Top Nanushuk

Nan 4

Nan 3

Nan 2

Nan 1

HRZ

LCU

TD?

J. Chmielowski, Alaska Division of Oil and Gas
**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%
- Permeability avg = 11 md
- Flowed 3,220 bopd (41-45 API), 1.26 mmscf/d

Sealing transgressive shale

Top Torok Fm
*(uppermost slope facies)*
HAVE WE SEEN JUST THE TIP OF THE ICEBERG?
- WILLOW, HORSESHOE TRENDS AMONG MANY MORE -

J. Chmielowski, Alaska Division of Oil and Gas

Public seismic line USGS 81-16; Total length 60 miles
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.
Critical new variant of topset play

Shelf-margin Sand Wedge, Up-dip Proximal Pinchout

Data are updated frequently and available for discounted purchase at [http://dggs.alaska.gov/gmc/seismic-well-data.php](http://dggs.alaska.gov/gmc/seismic-well-data.php)
• Of the recent discoveries, greatest promise is from proving up the basal Nanushuk topset play;

• No substitute for serendipity, but we need robust regional framework to understand & incorporate clues;

• North Slope underexplored, conventionals still surprising us;

• Nanushuk play – Larger prospects, more assessed oil resource, lots of undrilled leads and running room

• Tax Credit program 2D/3D seismic data release ongoing.