Nanushuk Formation
Brookian Topset Play,
Alaska North Slope

North American Prospect Expo 2017

Alaska Department of Natural Resources,
Division of Oil and Gas

NAPE, February 2017
Several exciting Nanushuk and Torok Formation discoveries are at different stages of delineation and development.
# Major Recent Nanushuk Discoveries

<table>
<thead>
<tr>
<th></th>
<th>Pikka</th>
<th>Willow</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operator</strong></td>
<td>Armstrong</td>
<td>ConocoPhillips</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Onshore Colville Delta</td>
<td>Onshore Northeast NPRA</td>
</tr>
<tr>
<td><strong>Depth to Reservoir</strong></td>
<td>~ 4,200 ft TVD</td>
<td>~ 3,600 ft TVD</td>
</tr>
<tr>
<td><strong>Trap type</strong></td>
<td>Stratigraphic (faults?)</td>
<td>Stratigraphic</td>
</tr>
<tr>
<td><strong>Net Pay</strong></td>
<td>&lt; 225 ft</td>
<td>42-72 ft</td>
</tr>
<tr>
<td><strong>Oil Gravity</strong></td>
<td>30 deg API</td>
<td>44 deg API</td>
</tr>
<tr>
<td><strong>Test Rate</strong></td>
<td>~ 2,100 bopd vertical; 4,600 bopd horizontal</td>
<td>&lt; 3,200 bopd vertical</td>
</tr>
<tr>
<td><strong>P50 Contingent</strong></td>
<td>1,438 MMBOR includes deeper horizons</td>
<td>300 MMBOR</td>
</tr>
<tr>
<td><strong>Recoverable Resource</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Expected Production</strong></td>
<td>up to 120,000 bopd</td>
<td>40,000-100,000 bopd</td>
</tr>
</tbody>
</table>
North Slope Petroleum Systems

Modified by Alaska Division of Oil and Gas staff from Bird and Houseknecht (2002) and Houseknecht (2003)
The Brookian sequence represents a wide range of clastic rocks shed from the ancestral Brooks Range into the Colville foreland basin during Cretaceous and Tertiary time.

Multiple formations make up the clinoformal succession, 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.

Nanushuk tends to have superior reservoir quality due to matrix winnowing and less compaction (shallower burial)
Cretaceous Brookian Sequence - Line A -

West

Grizzly 1
TVD 7,987 ft

Schrader Bluff, middle

Heavenly 1
TVD 9,372 ft

Malguk 1
TVD 11,296 ft

East

3 sec TWT

Flatten Datum

UK
Schrader Bluff, lower

Tuluvak

Seabee

Nanushuk Fm
Topsets

Torok Fm
Slope foresets & Basin-floor bottomsets

LK

GRZ L. Kingak

Shublik

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

MCU = mid-Campanian unconformity

Image from David Houseknecht, USGS; courtesy GeoExpro and Western-Geco Multiclient
After David Houseknecht, USGS

Nanushuk topset play

Erosional limit of Seabee and younger strata onshore

Torok slope

Hue-GRZ basin floor source facies

Sand-prone lowstand wedge in foredeep

After David Houseknecht, USGS
**Basal Nanushuk Seismic Anomalies - Line B, Northeast NPRA -**

- **Inigok 1**
- **North Inigok 1**
- **North Kalikpik 1**

**Key Features:**
- **Tuluvak & Seabee Fms**
- **Nanushuk Fm**
- **Torok Fm**
- **HRZ - Hue Shale (oil source rock)**
- **Fish Creek slumps**

**Public seismic line USGS 81-27**
Nanushuk Formation

- Lower Cretaceous (Albian – Cenomanian)
- Shallow marine to nonmarine topsets with abundant reservoir-prone sandstone
- Genetic equivalent of Torok Formation slope foresets and basinal facies
- Nanushuk + Torok represent a major clinoformal succession that filled the western Colville foreland basin by prograding west to east, along basin axis
- Fully marine at base, transitions upward to mainly nonmarine, capped by marginal marine transgressive interval

LePain et al. (2009) after Huffman et al. (1985)
Nanushuk Fm Reservoir Quality

The graph illustrates the relationship between permeability (in md) and porosity (in %) for various locations and wells within the Nanushuk Fm reservoir. Different markers and colors represent different locations and samples, allowing for a visual analysis of the reservoir quality across the study area.
Qugruk 3 announced as multi-horizon discovery April 2013; Play type is characterized by stratigraphically-trapped shelf margin/lowstand wedge sandstones in lower Nanushuk and underlying sandy slope Torok Formation.
Willow discovery announced January, 2017 was a follow-up of this 2002 discovery. Play type is characterized by stratigraphically-trapped lowstand shoreface shelf margin sandstones in lower Nanushuk Formation.

Lower part of Nanushuk Fm (basal topset facies)

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

Top Torok Fm (uppermost slope facies)

## Undeveloped Nanushuk-Torok Oil

<table>
<thead>
<tr>
<th>Formation</th>
<th>Accumulation</th>
<th>Location</th>
<th>Explorer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanushuk Fm</td>
<td>Pikka</td>
<td>State/ASRC onshore</td>
<td>Armstrong/Repsol</td>
</tr>
<tr>
<td>&quot; &quot;</td>
<td>Willow</td>
<td>NPRA onshore</td>
<td>ConocoPhillips</td>
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<tr>
<td>&quot; &quot;</td>
<td>Umiat</td>
<td>NPRA onshore</td>
<td>US Navy</td>
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<tr>
<td>&quot; &quot;</td>
<td>Simpson</td>
<td>NPRA onshore</td>
<td>US Navy</td>
</tr>
<tr>
<td>&quot; &quot;</td>
<td>Fish Creek</td>
<td>NPRA onshore</td>
<td>US Navy</td>
</tr>
<tr>
<td>Torok Fm</td>
<td>Nuna-Moraine</td>
<td>NPRA onshore</td>
<td>Caelus, ConocoPhillips</td>
</tr>
<tr>
<td>&quot; &quot;</td>
<td>Cassin</td>
<td>NPRA onshore</td>
<td>ConocoPhillips</td>
</tr>
<tr>
<td>&quot; &quot;</td>
<td>Smith Bay</td>
<td>State waters</td>
<td>Caelus</td>
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</tbody>
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Closely Related Brookian Plays

Nanushuk lowstand shelf-margin wedges & incised, back-stepping facies

Seabee & younger slope-apron fans and slope-incision facies

Torok slope-apron & basin-floor fans

Image from David Houseknecht, USGS; courtesy GeoExpro and Western-Geco Multiclient
USGS and BOEM estimate Arctic Alaska’s mean undiscovered, technically recoverable conventional resources at nearly 40 billion barrels of oil and 207 trillion cubic feet of gas.

The most recent assessments of North Slope onshore areas (state lands, NPRA, and ANWR coastal plain) estimate total mean resources of 15.9 billion barrels of oil + NGL.

Of this, various Brookian plays account for 11.7 billion barrels (mean), of which 2.6 billion barrels is assessed on central North Slope state lands.

The Nanushuk topset play of the central and western North Slope is more prospective than these assessments recognized. For example, at 300 million barrels recoverable, the Willow discovery far exceeds even the upside (F5) estimate for the Stratigraphic Brookian Topset play in NPRA.