Core to Log Integration in Alaska's North Slope Nanushuk Formation
Using High Resolution Petrophysical Profiling*

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Abstract

Proper integration of petrophysical data acquired at log and sample scale is key to generating representative models for subsurface exploration, development, and production. Though critical in delivering ground truth assessment of various properties and their spatial variability under the well log resolution, lab-based measurement programs are often adversely affected by sparse sampling and relatively long turnaround times. Fast petrophysical profiling of the core surface offers an intermediate tool with data outputs which can be readily integrated with well logs on the one hand while being leveraged for picking plug location on the other when enhanced characterization is desired. In this paper, we present a data set combining publicly available log and plug data with the result of a petrophysical profiling campaign conducted on 40 feet of slabbled core from Alaska’s North Slope Nanushuk Formation which comprises both sandstone and shale intervals. The petrophysical profiling was done with an AutoScan system at a 5mm spatial frequency and included P- and S-wave velocity, permeability, reduced Young’s modulus through a unique rebound technique (Impulse hammer), as well as FTIR spectra for mineralogy. The remarkable correlation between permeability values obtained from plugs and AutoScan profiling provides a benchmark for exploiting the superior spatial coverage of AutoScan data and define physically based rock types which can be ultimately used for sampling and to establish core to log transforms. The integration between AutoScan and wireline log triple combo (gamma ray / density / resistivity) data reveals in particular a large variability in mechanical and compositional layering and forms the basis for transforms that can then be extended over the entire well length. After a thorough review and integration of the available plug, core and well log data, we conclude the paper by outlining a generic workflow aimed at providing an early physically based option for decision making.
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1 New England Research
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NER Company Overview

- **Equipment**
  - AutoLab
  - AutoScan
  - BenchLab
  - Custom

- **Measurements**
  - Routine
  - ‘In-house’ routine
  - Custom workflows

- **R&D, consulting**
  - Tool development
  - Modeling
  - Data interpretation

- Small integrated group
- ~30 years in operation
- Custom projects and systems
- Diverse rock physics experience
- Variable project size
Whole Core CT Scanning & Core Description

EARLY Upscaling and Core-Log Integration

FAST Rock Typing Through Petrophysical Core Scanning

SMART Sampling Using Petrophysical Rock Types

Plug Measurements and Trend/Model Building Per Rock Type

Plug to Core Integration
AutoScan Overview
A unique integrated tool for rapid reservoir characterization...

- mm to cm scale core scanning & mapping
- Permeability
- P- and S-wave velocity
- Electrical Resistivity
- FTIR
- Impulse Hammer
- Core Photography
- Grain size
- Fracture Detection
- Custom Probes
- Rock Typing and Plug Selection
  Optimize special core analysis
- Core-Log Integration and Upscaling
  Ties to geologic models, depth shifting
... Across specialties in the appraisal workflow

**Geology**
Alongside sedimentary description, FTIR logging/mapping enables compositional rock typing and provides a first step in reservoir description and quality assessment, incl. heterogeneity

**Petrophysics & Reservoir Engineering**
Petrophysical rock typing and core to log integration can be performed on the basis of direct velocity, resistivity and permeability logging/mapping

**Geomechanics**
Geomechanical modeling for completion/stimulation strategy and compaction forecasting can be informed by direct permeability, velocity and mechanical properties logging/mapping
North Slope Stratigraphy

Ahmadov et al, 2020

Modified by Alaska Division of Oil and Gas staff from Bird and Houseaknecht (2002) and Houseaknecht (2003)

LePain etal (2018)
Seismic Section of Depositional Environment

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

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

Torok slope-apron & basin-floor fans

Facies associations in the Nanushuk Formation. After LePain and others (2009), based on Huffman and others (1988). The Nanushuk is portrayed schematically as a regressive succession capped by thinner transgressive deposits in its uppermost part.

Seismic and outcrop data demonstrate the existence of lowstand erosion surfaces across which shallow and marginal-marine facies are juxtaposed on deeper water facies.

AutoScan-based Measurements from Core

- Reconcile petrology and rock physics observations for rock properties
- Quantify rock properties at a scale way below wireline log resolution and below plug scale
- FTIR + Velocity + Impulse Hammer + Permeability
- FTIR = Clay + Carbonate + Silicate + Oil Signature
- Velocity = Vp + Vs
- Measurements obtained every 5 mm for a total of 2400 measurements on 40ft core interval
- Comparison of AutoScan data to published data of LePain et al. (2018)* and vailable triple-combo wireline logs from “Umiat 18” well

Triple combo wireline well log suite available for Umiat 18 well where core in this study is used from.
Nanushuk Formation Well Logs and Core Location

Triple combo wireline well log suite available for Umiat 18 well where core in this study is used from.
Rock Physics Diagnostics

Triple combo wireline well log suite available for Umiat 18 well where core in this study is used from.
Rock Physics Diagnostics

Triple combo wireline well log suite available for Umiat 18 well where core in this study is used from.
Nanushuk Formation Core

759ft-769ft
771ft-780ft
780ft-789ft
789ft-798ft
AutoScan-derived Data
Richness of AutoScan-derived Data
Richness of AutoScan-derived Data

At 5mm resolution AutoScan provides 30x more resolution compared to wireline logs!
Separating Lithologies by Acoustic Signatures

Ahmadov et al, 2020

Clay

Sandstones

Shales
Separating Lithologies by Acoustic Signatures

Ahmadov et al., 2020
Separating Lithologies by Acoustic Signatures

Ahmadov et al., 2020
Acoustic and Elastic Signatures

Shales

Sandstones

Vp/Vs vs Estar, GPa

Clay
Hydraulic and Elastic Signatures

Ahmadov et al, 2020

Clay

Sandstones

Shales
Sandstone vs Shales in Acoustic Domain

Vclay<30%

Vclay>30%

Log Permeability, md
Permeability Comparison

Ahmadov et al., 2020

AutoScan

Permeability, md (This study)

Depth, ft

-2 0 2 4

Sandstones

Shales

Plugs

Permeability, md (LePain et al., 2018)

Clay

0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

ner.com
Permeability Comparison

Porosity was computed from porosity-permeability transform (from LePain et al, 2018) applied to AutoScan-derived permeability data.
Porosity was computed from porosity-permeability transform (from LePain et al, 2018) applied to AutoScan-derived permeability data.
Cross-bedding between 791–782 feet. These represent foresets to either 2D or 3D dune.

>2 orders of variation in permeability over 9ft interval corresponding to dunes. Almost 50% variation in elastic properties over the same interval.
Well-defined flooding surface at ~777 feet. The zone is represented by condensed section.
What's next?

Can we take this further to Rock Physics, Geophysics and Geomechanics domain?
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