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

R. Ahmadov[1,2], S. Carhart[3], K. Johnson[4], L. Louis[1], and G. Boitnott[1]

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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 slabbed 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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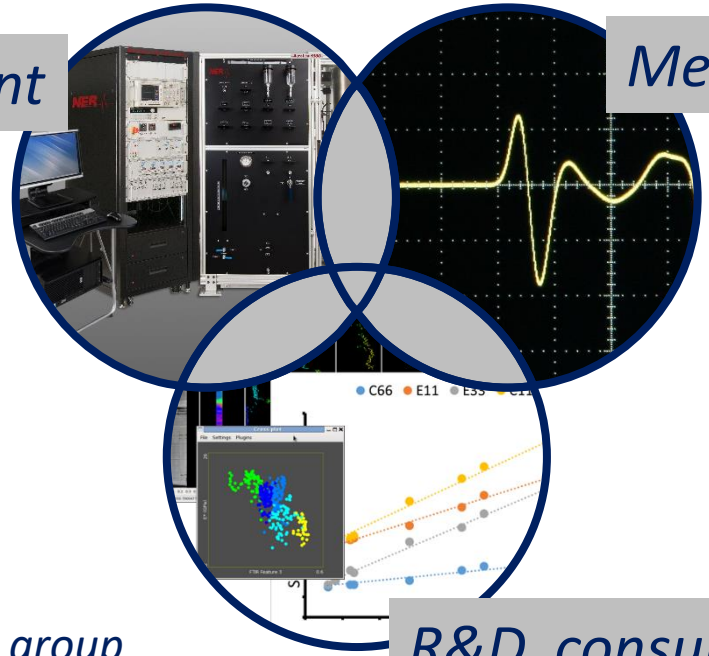
NER Company Overview

Equipment

- AutoLab
- AutoScan
- BenchLab
- Custom



Measurements

- Routine
- ‘In-house‘ routine
- Custom workflows

R&D, consulting

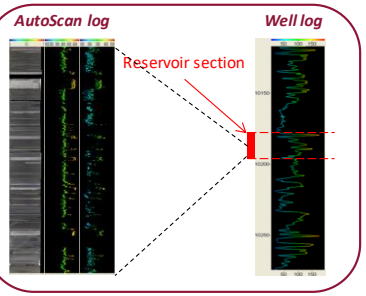
- Tool development
- Modeling
- Data interpretation

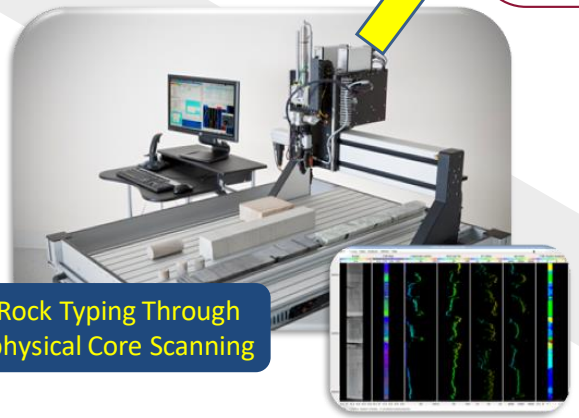
- Small integrated group
- ~30 years in operation
- Custom projects and systems
- Diverse rock physics experience
- Variable project size

Big Picture Workflow

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

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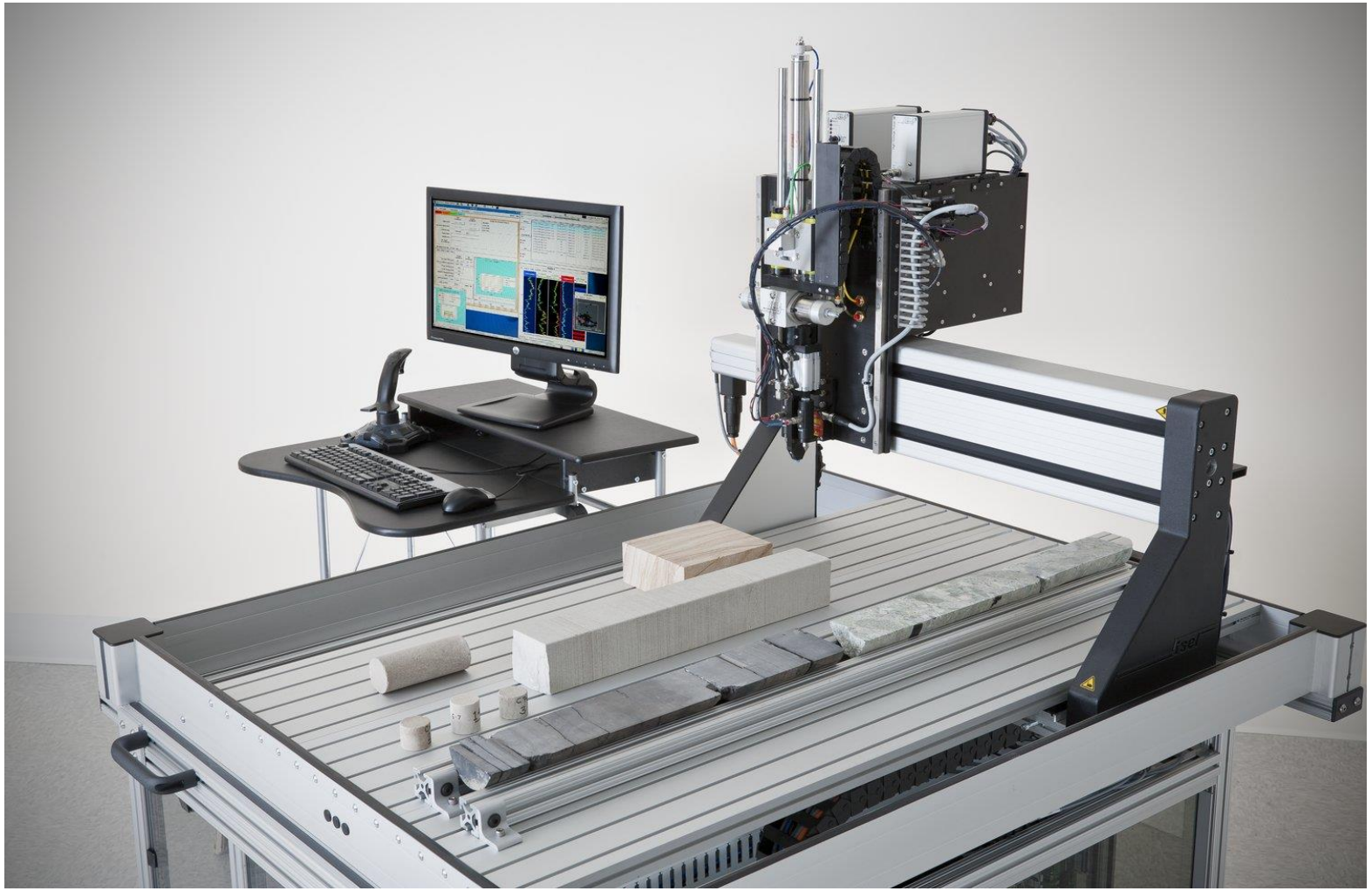
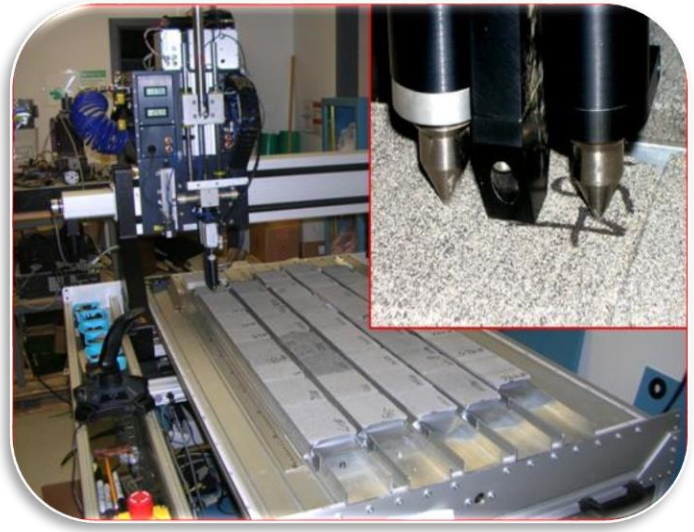
AutoScan Overview

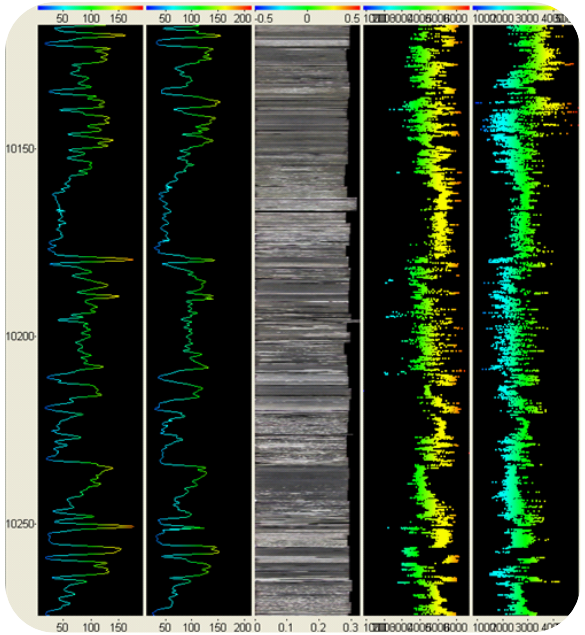


A unique integrated tool for rapid reservoir characterization…



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



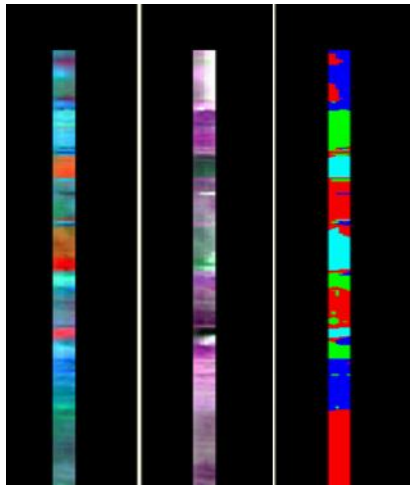
- Rock Typing and Plug Selection
  Optimize special core analysis

- Core-Log Integration and Upscaling
  Ties to geologic models, depth shifting

… Across specialties in the appraisal workflow

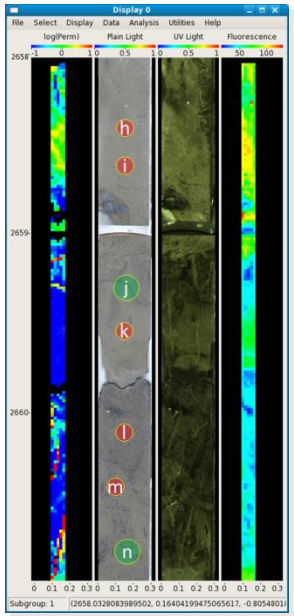
Geology

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



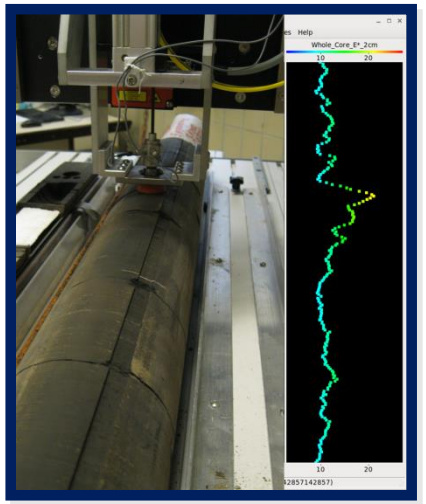
Petrophysics & Reservoir Engineering

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



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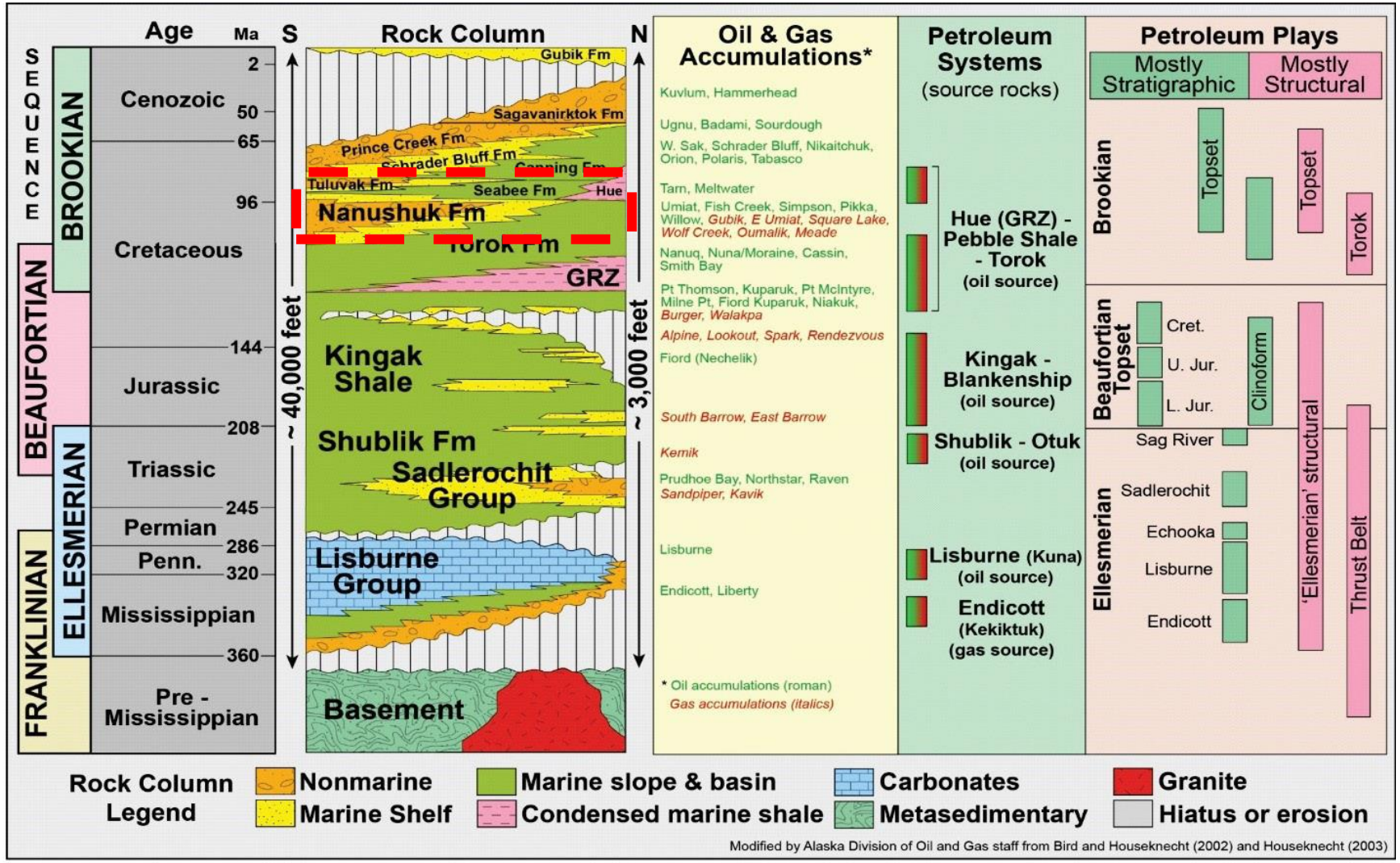
North Slope Stratigraphy



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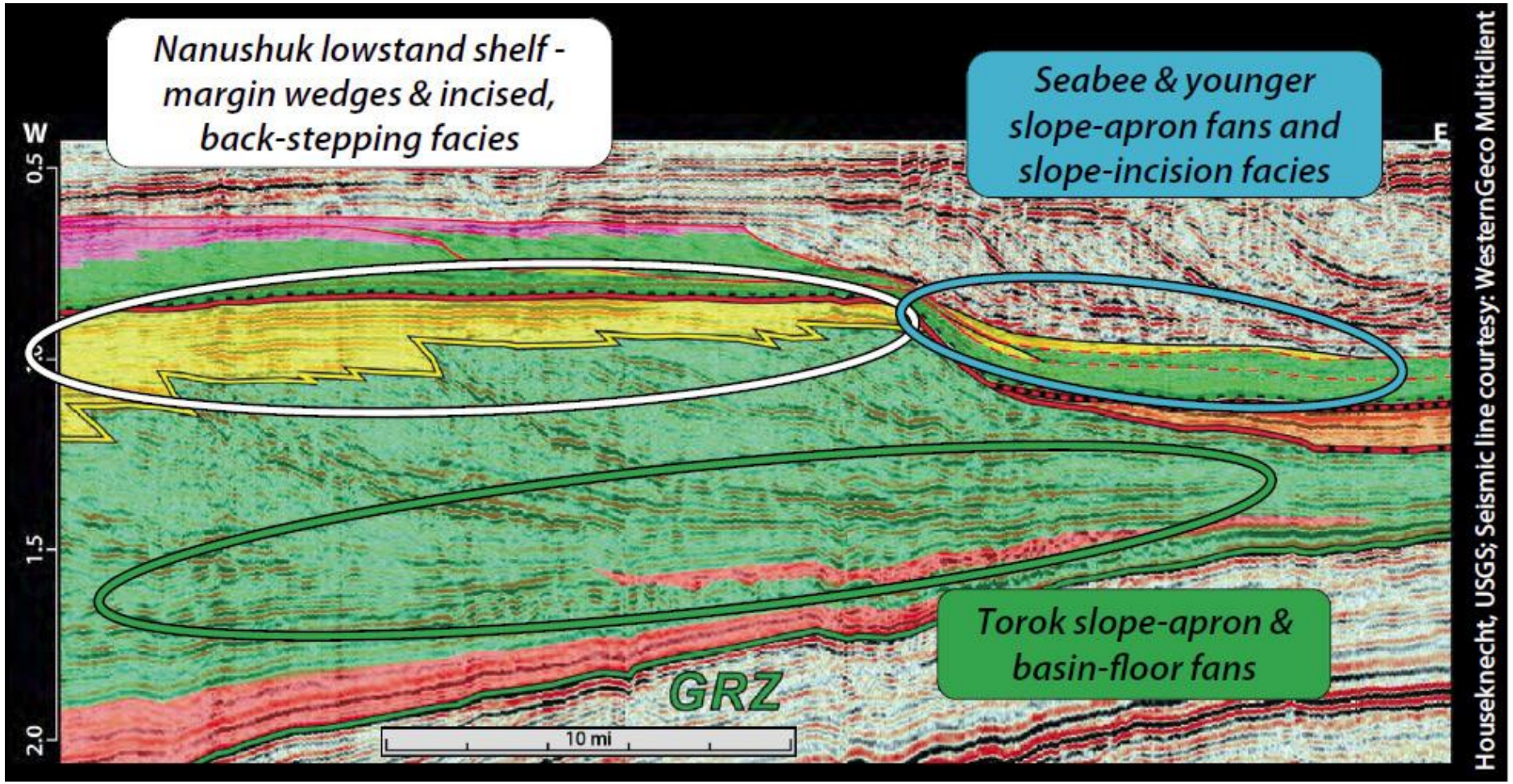
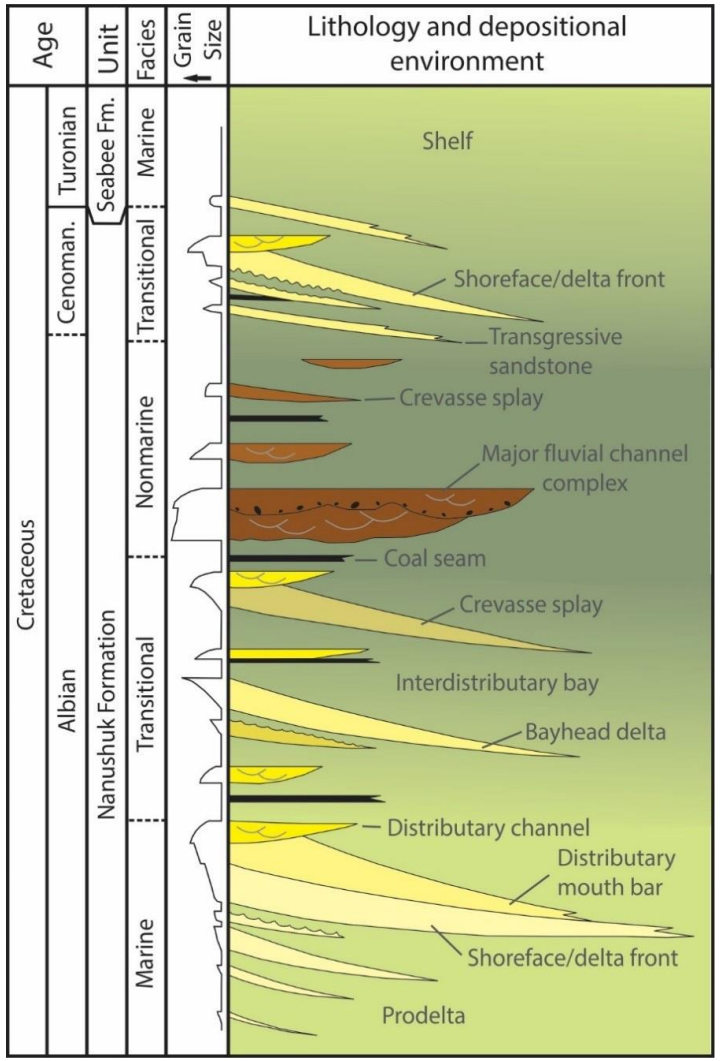
LePain etal (2018)

Seismic Section of Depositional Environment



LePain etal (2018)

Facies Architecture of Nanushuk Formation



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.

LePain etal (2018)

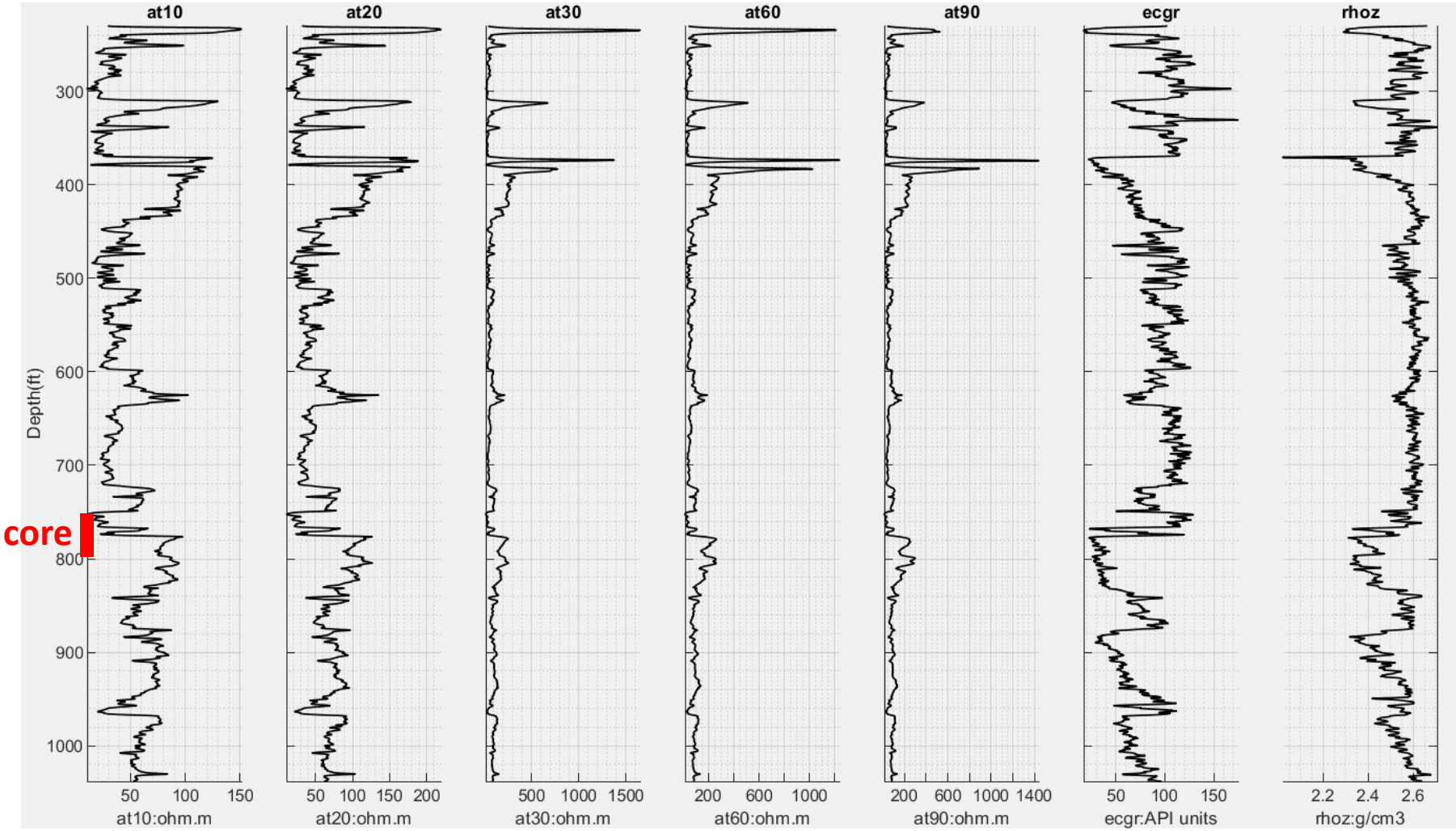
AutoScan-based Measurements from Core

- 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 etal (2018)** and vailable triple-combo wireline logs from “Umiat 18” well

**LePain, D.L., Decker, P.L., and Helmold, K.P., 2018, Brookian Core Workshop: Depositional setting potential reservoir facies, and reservoir quality in the Nanushuk Formation (Albian-Cenomanian), North Slope, Alaska: Alaska Division of Geological & Geophysical Surveys Miscellaneous Publication 166, 58 p.*

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.



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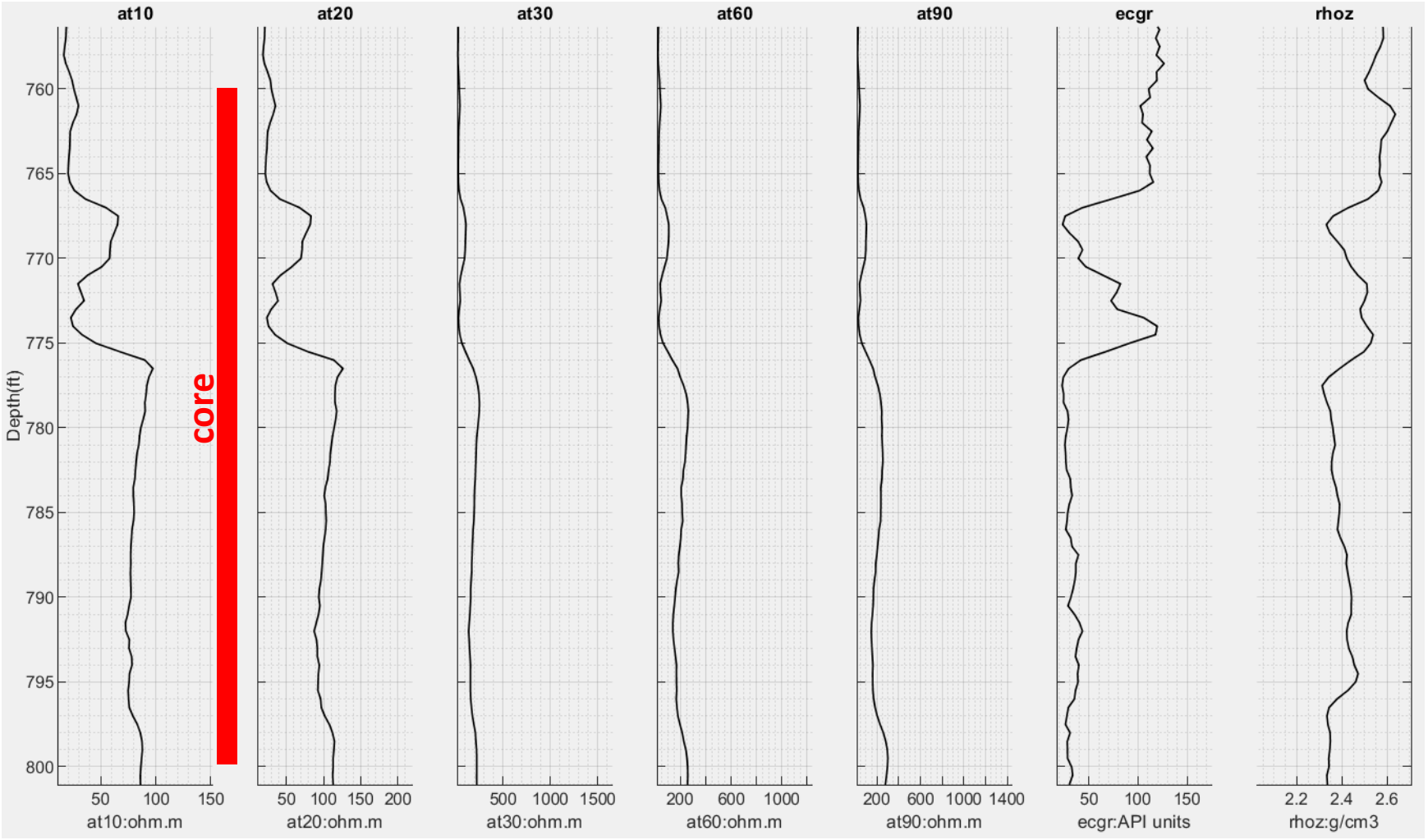
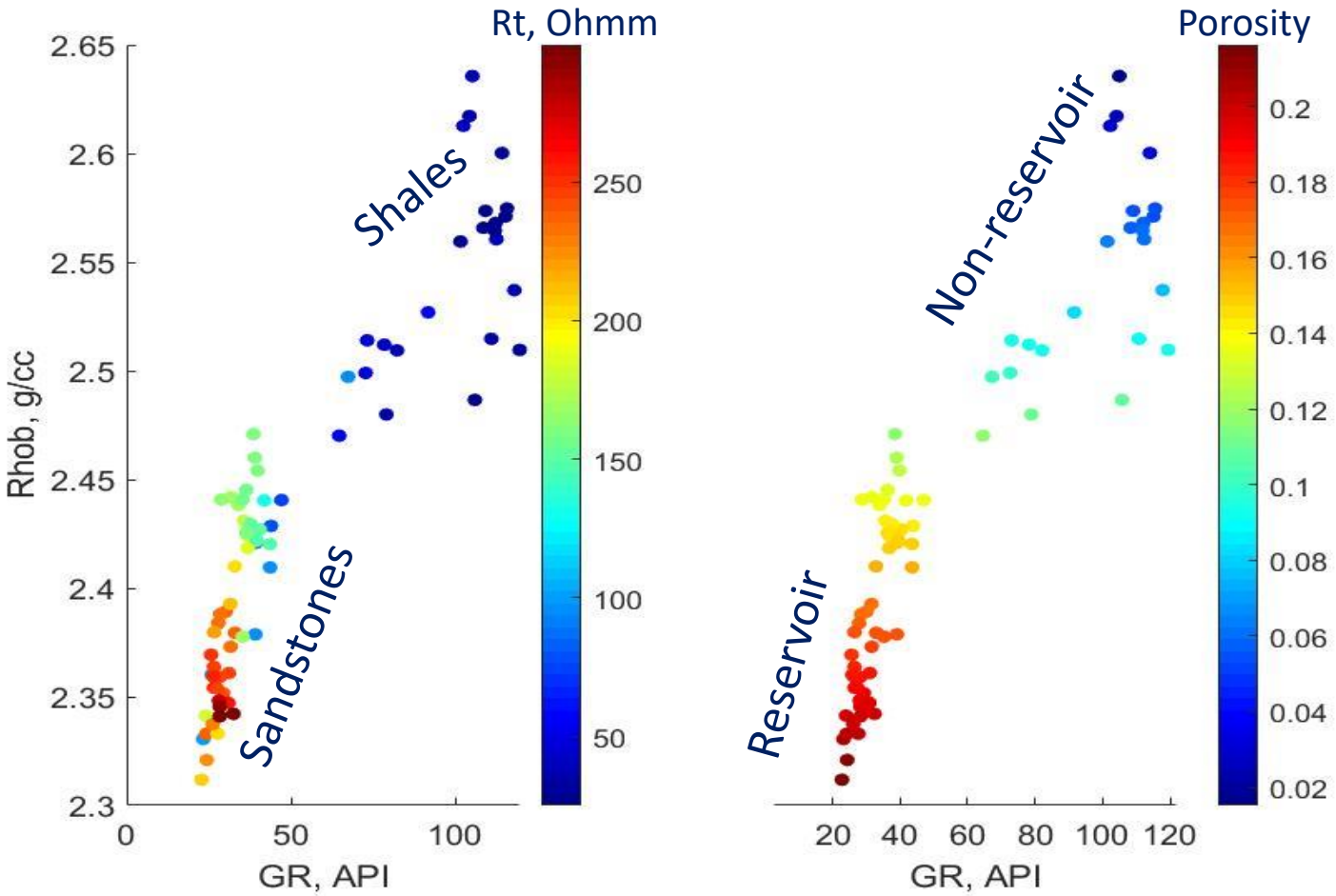


Rock Physics Diagnostics

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



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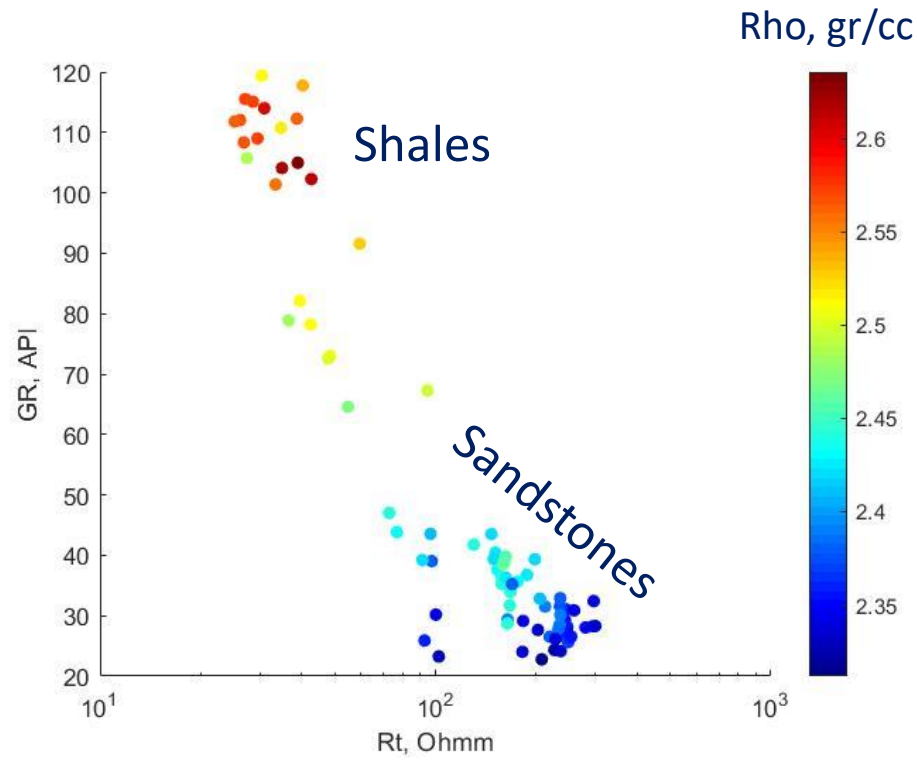
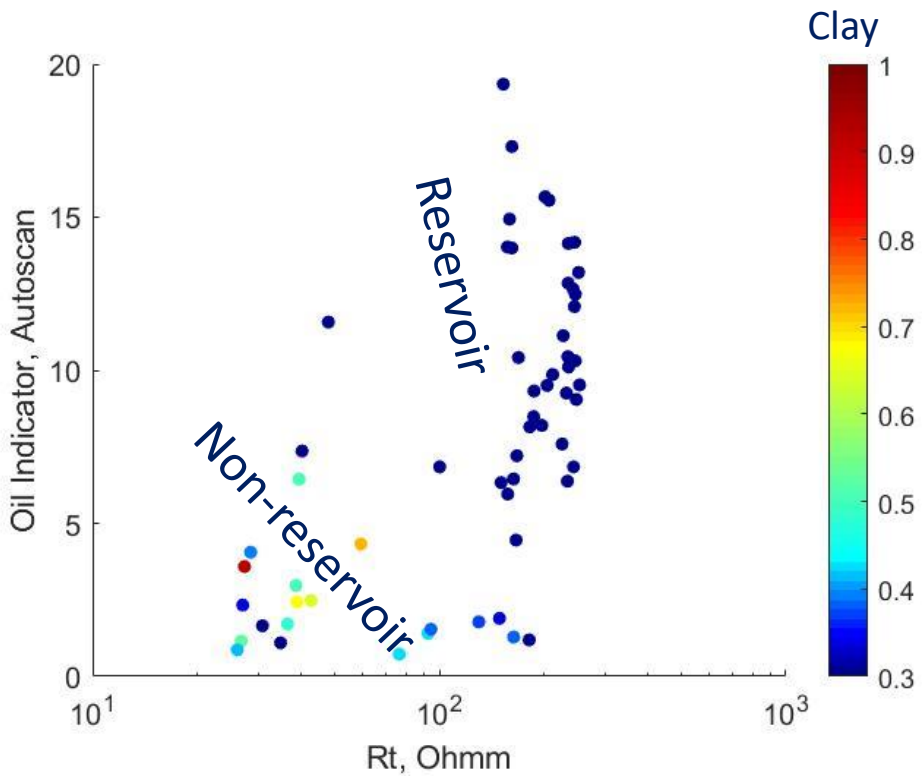
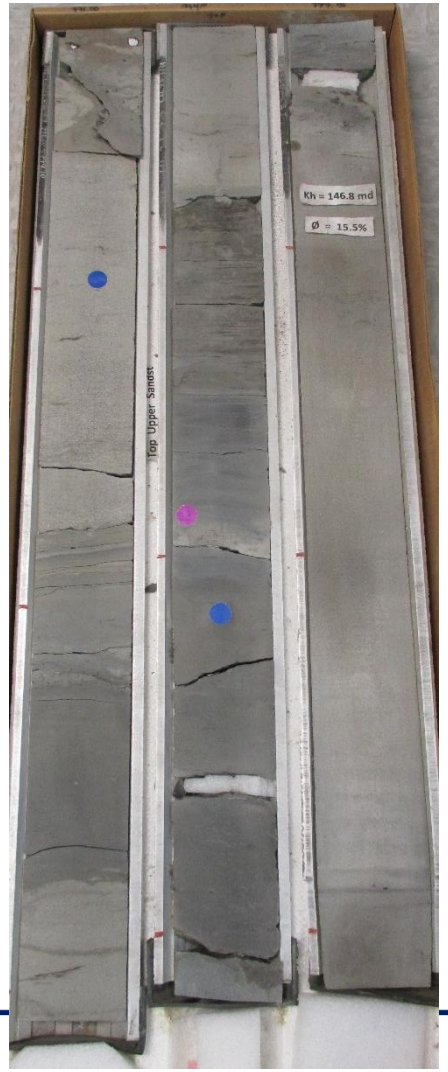




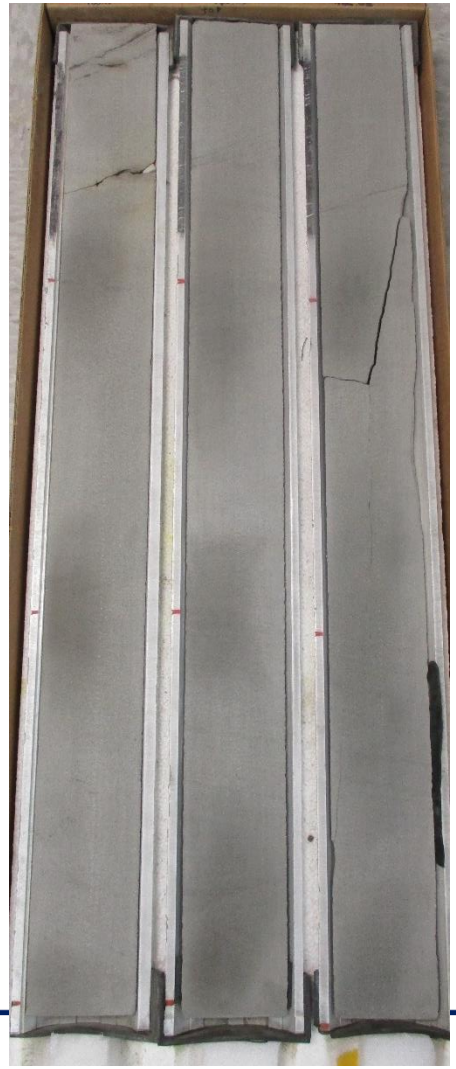
Nanushuk Formation Core

759ft-769ft

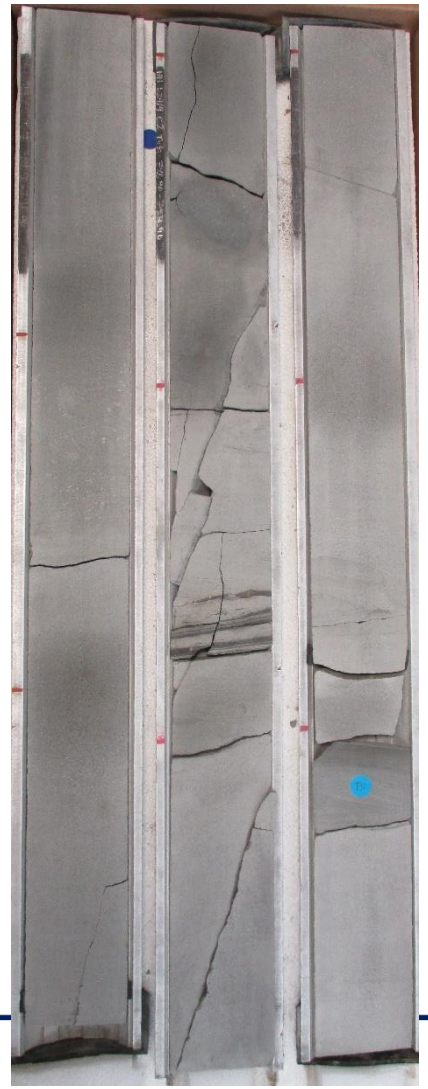
771ft-780ft



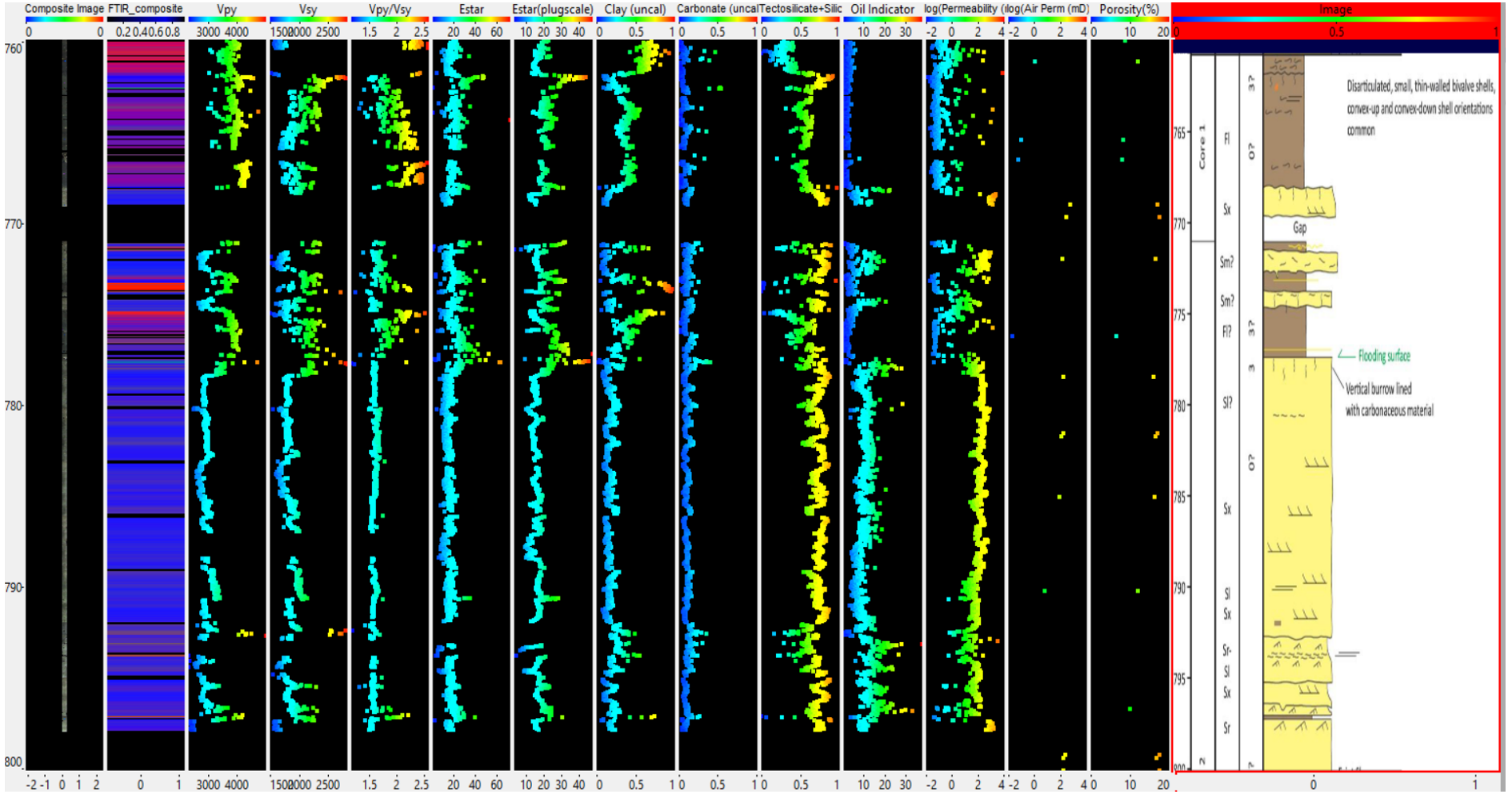
780ft-789ft



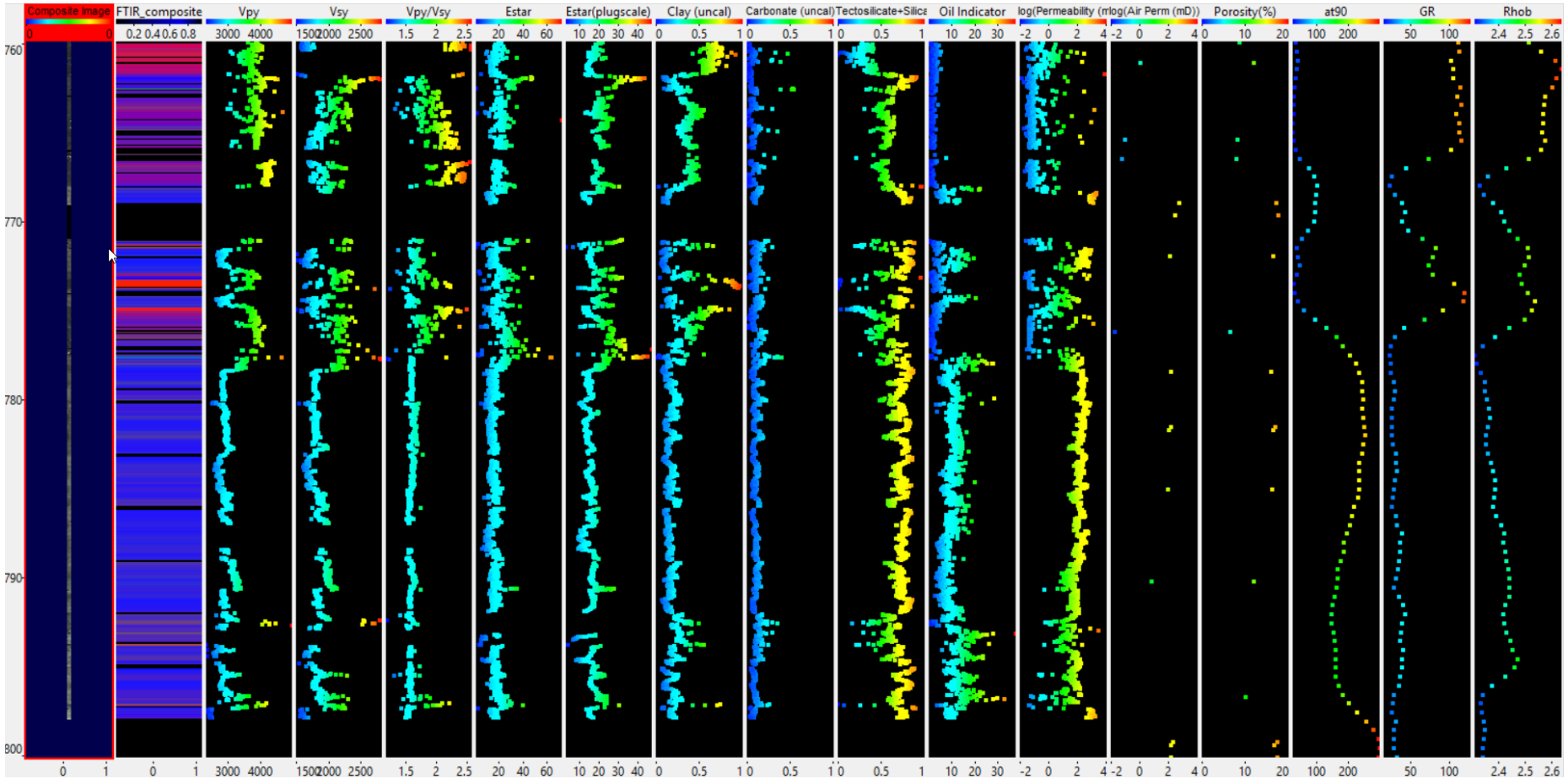
789ft-798ft



AutoScan-derived Data



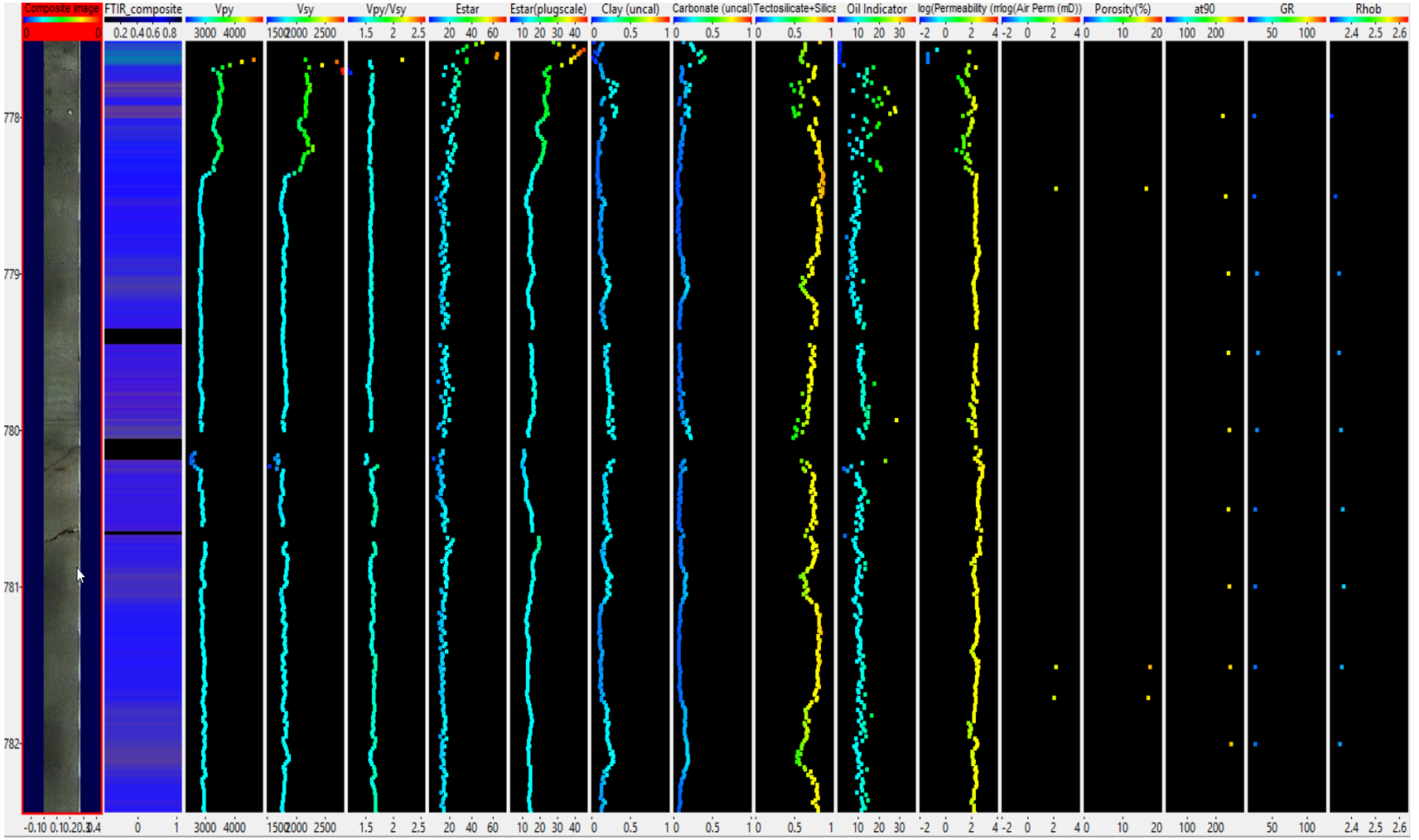
Richness of AutoScan-derived Data



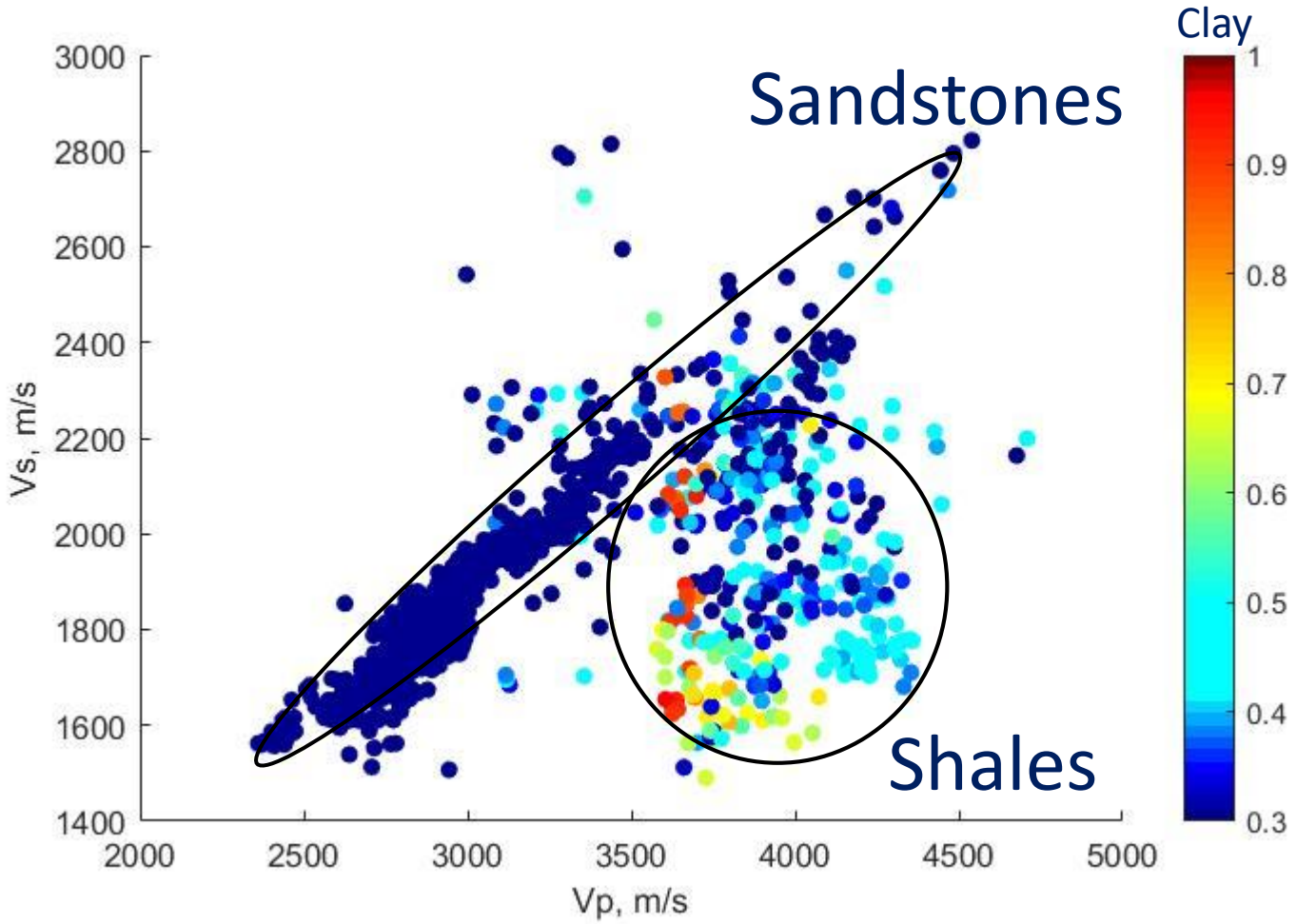
Richness of AutoScan-derived Data

At 5mm resolution AutoScan provides 30x more resolution compared to wireline logs!

5 ft core interval



Separating Lithologies by Acoustic Signatures



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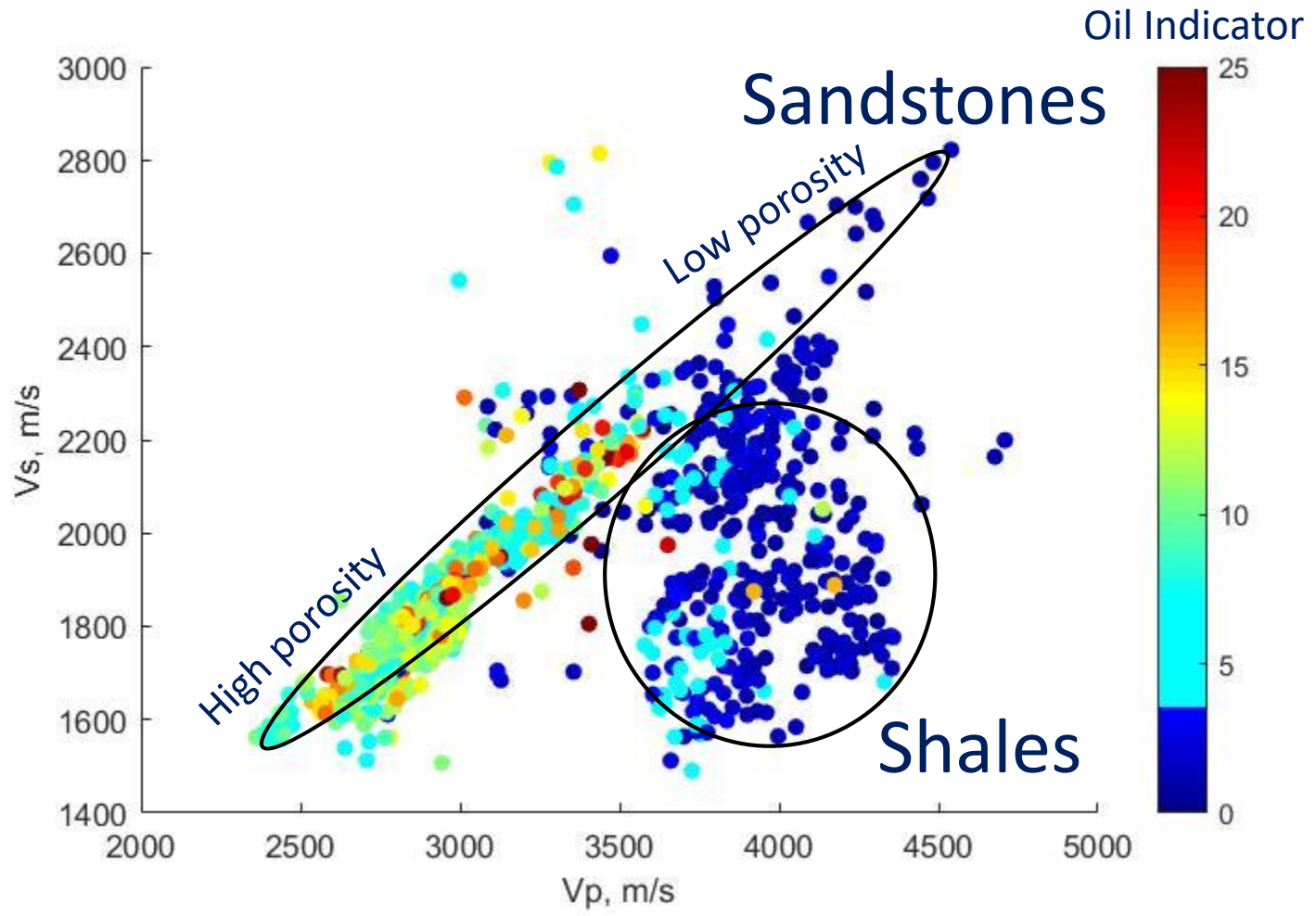

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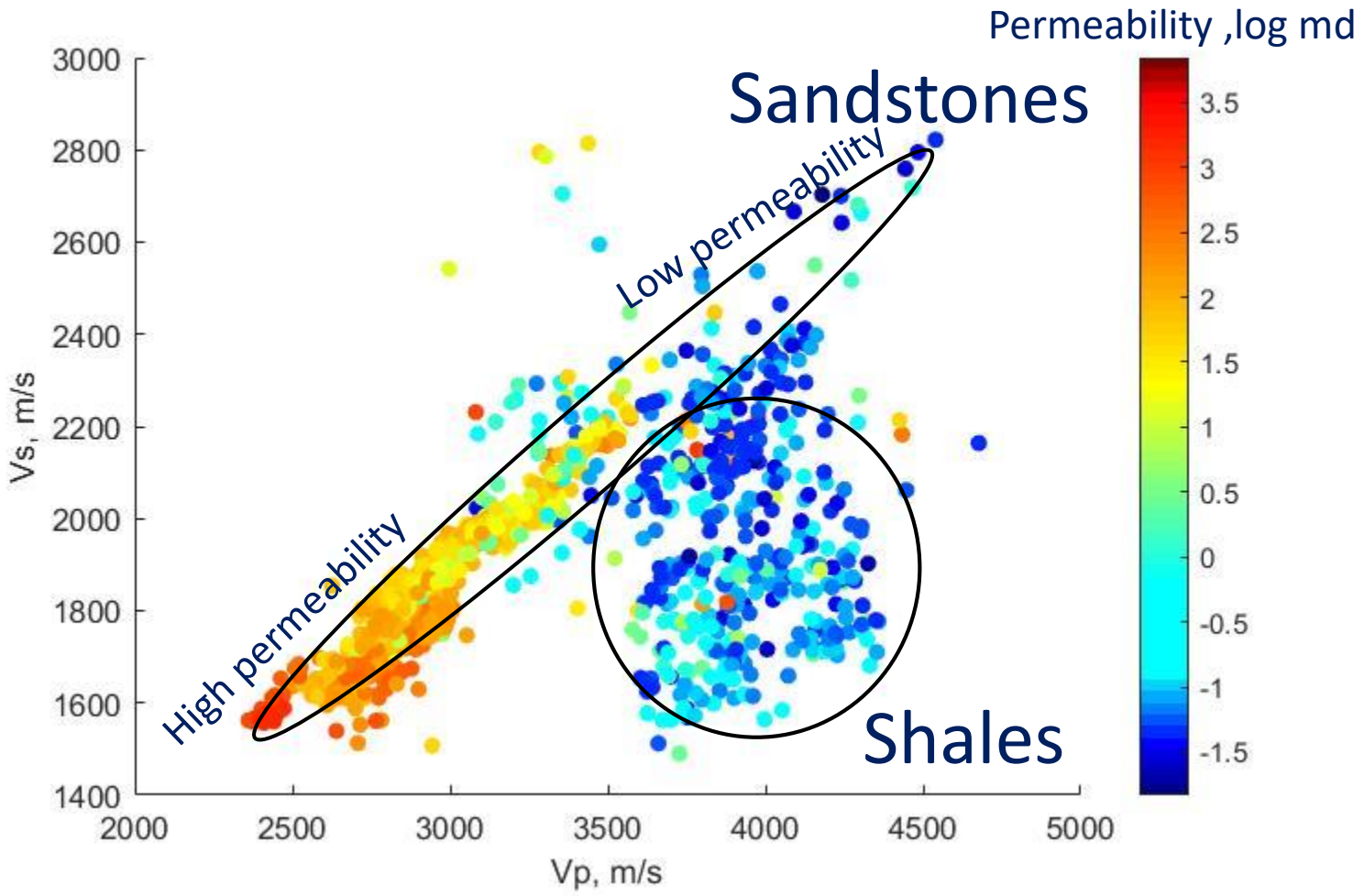

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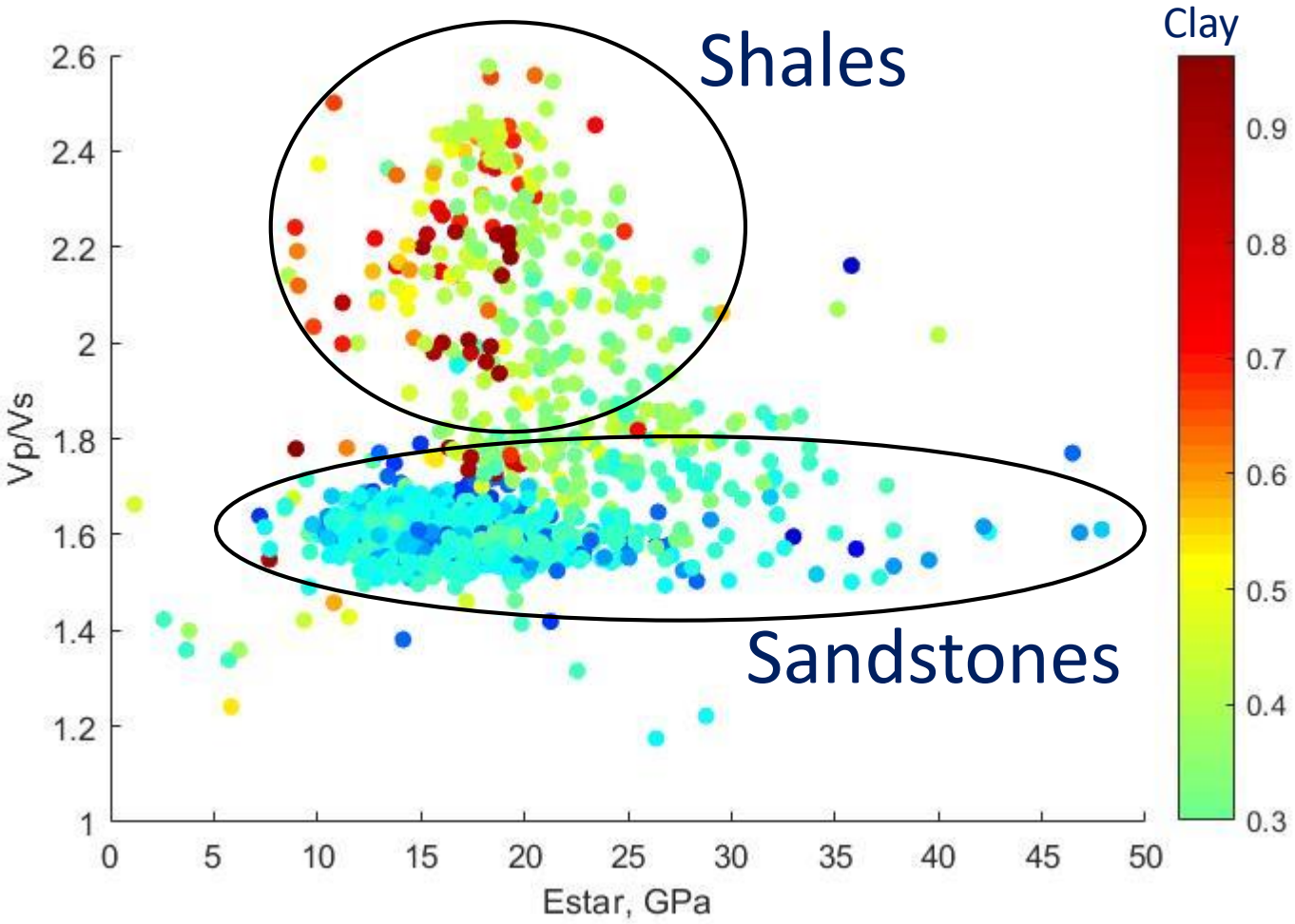
Acoustic and Elastic Signatures



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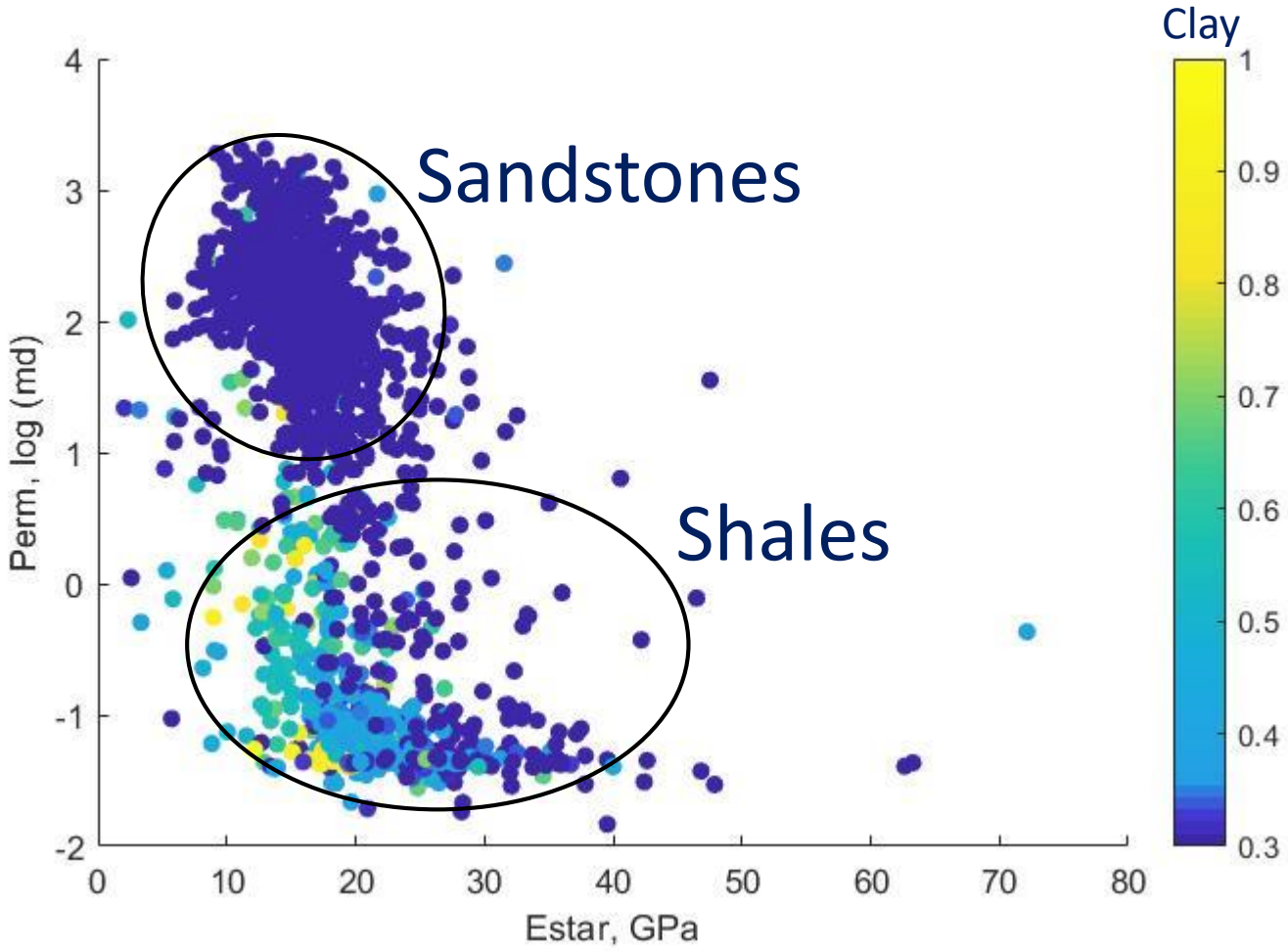
Hydraulic and Elastic Signatures



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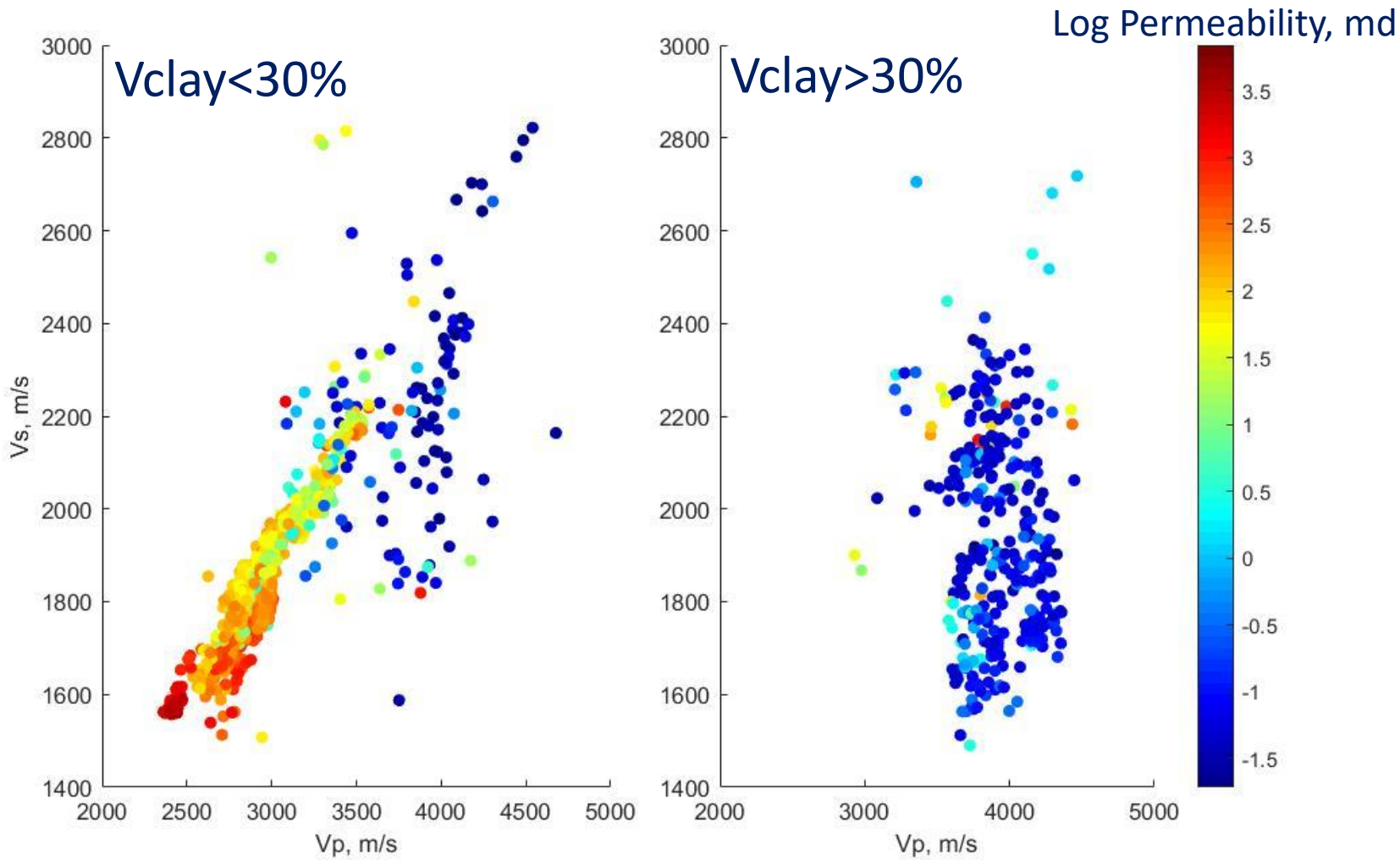
Sandstone vs Shales in Acoustic Domain



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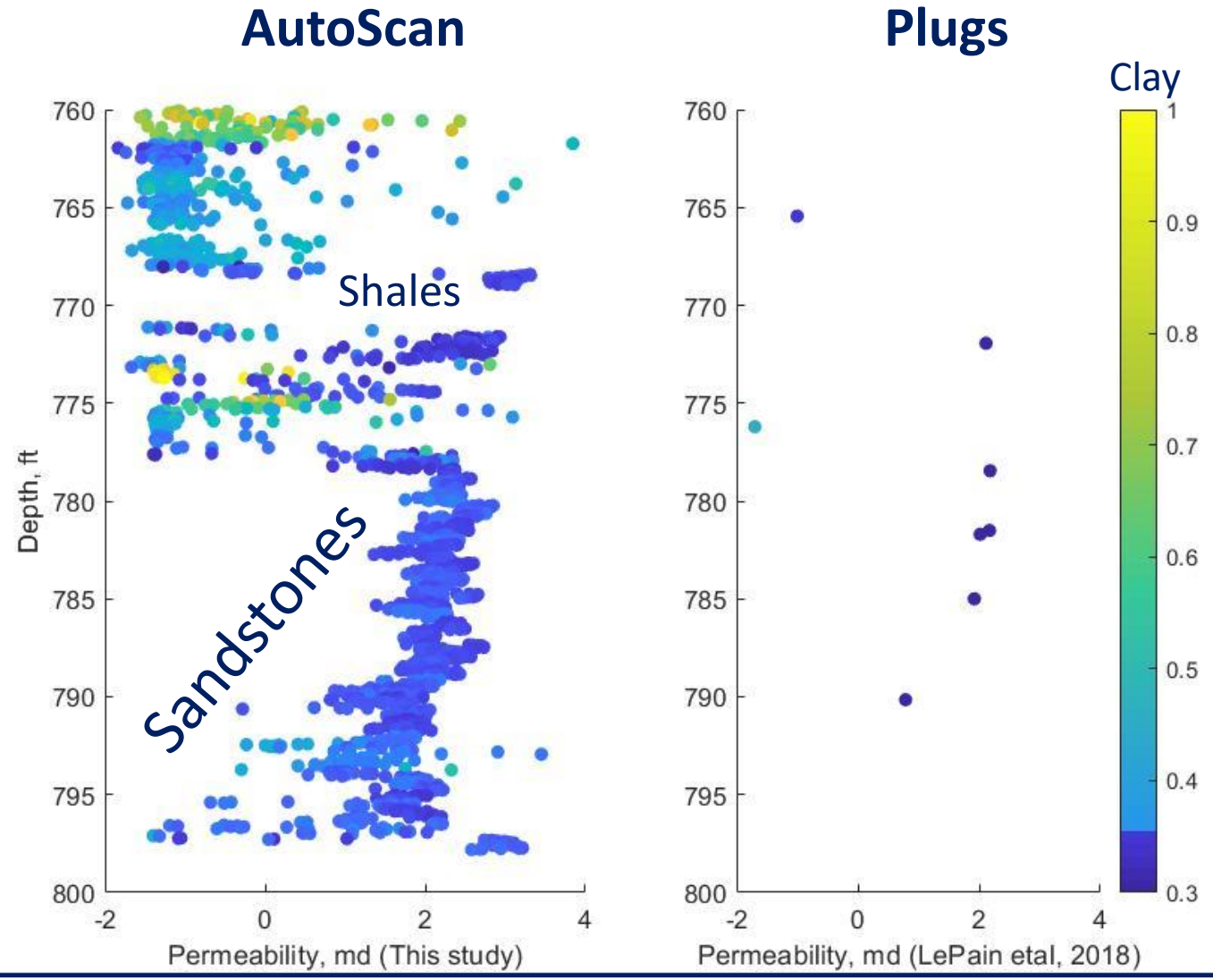
Permeability Comparison



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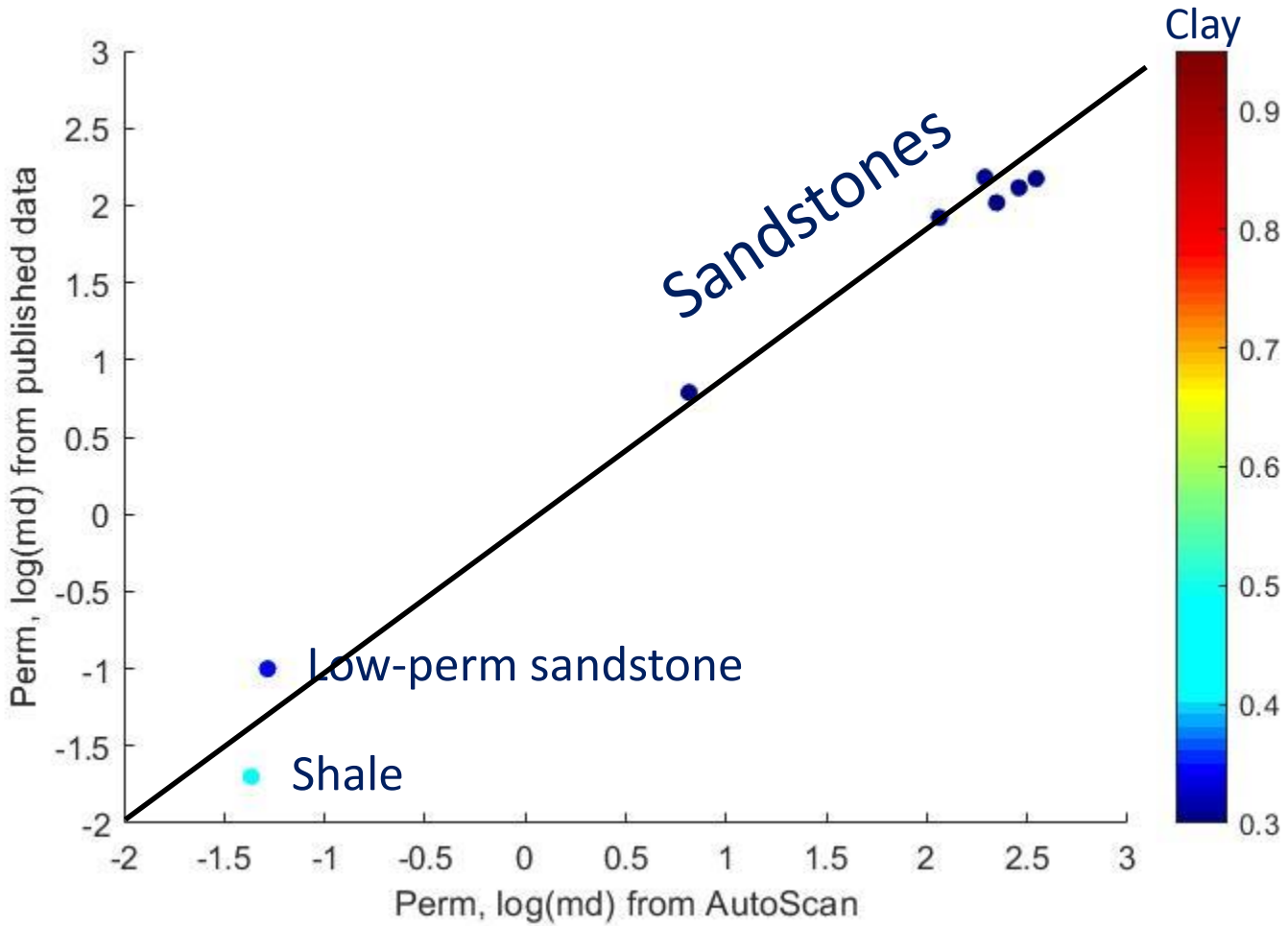
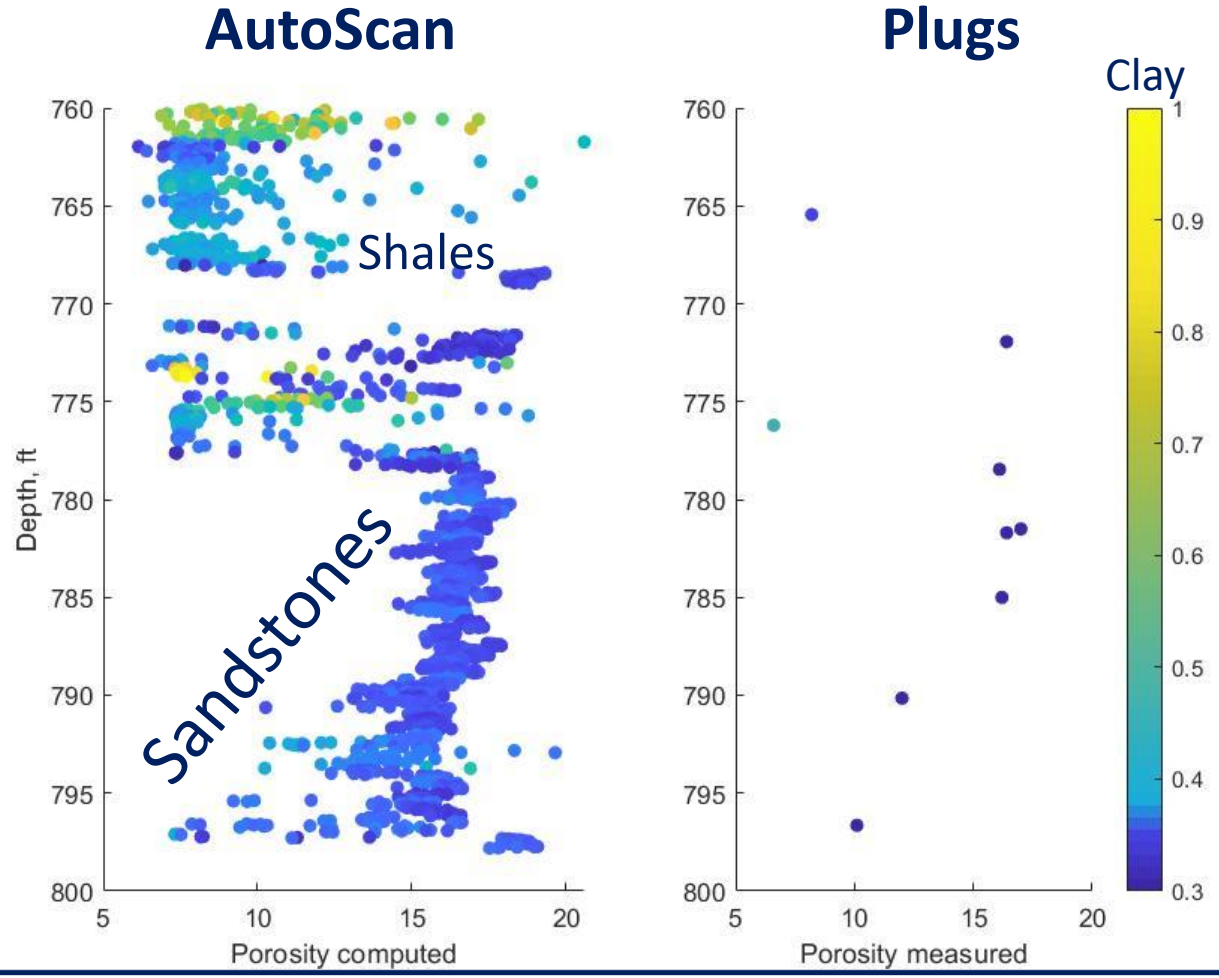


LePain, D.L., Decker, P.L., and Helmold, K.P., 2018, Brookian Core Workshop: Depositional setting potential reservoir facies, and reservoir quality in the Nanushuk Formation (Albian-Cenomanian), North Slope, Alaska: Alaska Division of Geological & Geophysical Surveys Miscellaneous Publication 166, 58 p.

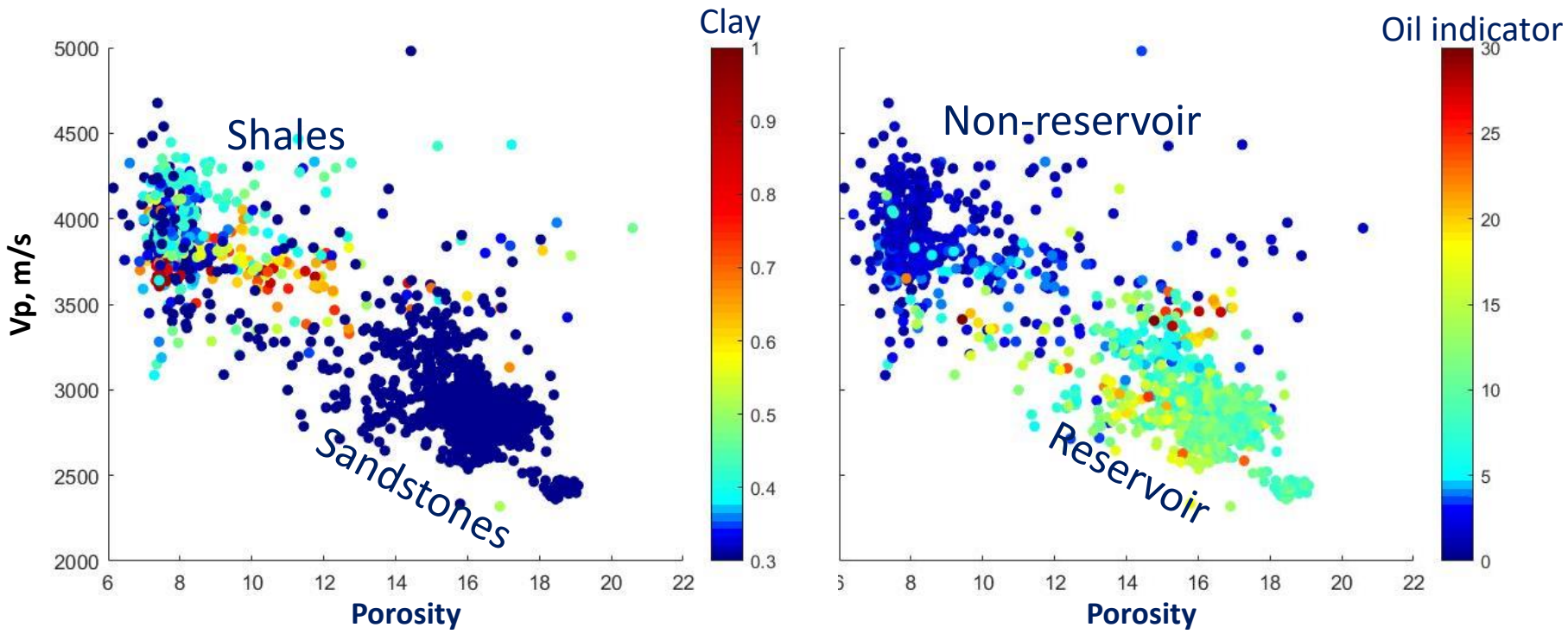
Porosity Comparison

Porosity was computed from porosity-permeability transform (from LePain etal, 2018) applied to AutoScan-derived permeability data



Lithology Differentiation – Rock Typing

Porosity was computed from porosity-permeability transform (from LePain eta, 2018) applied to AutoScan-derived permeability data



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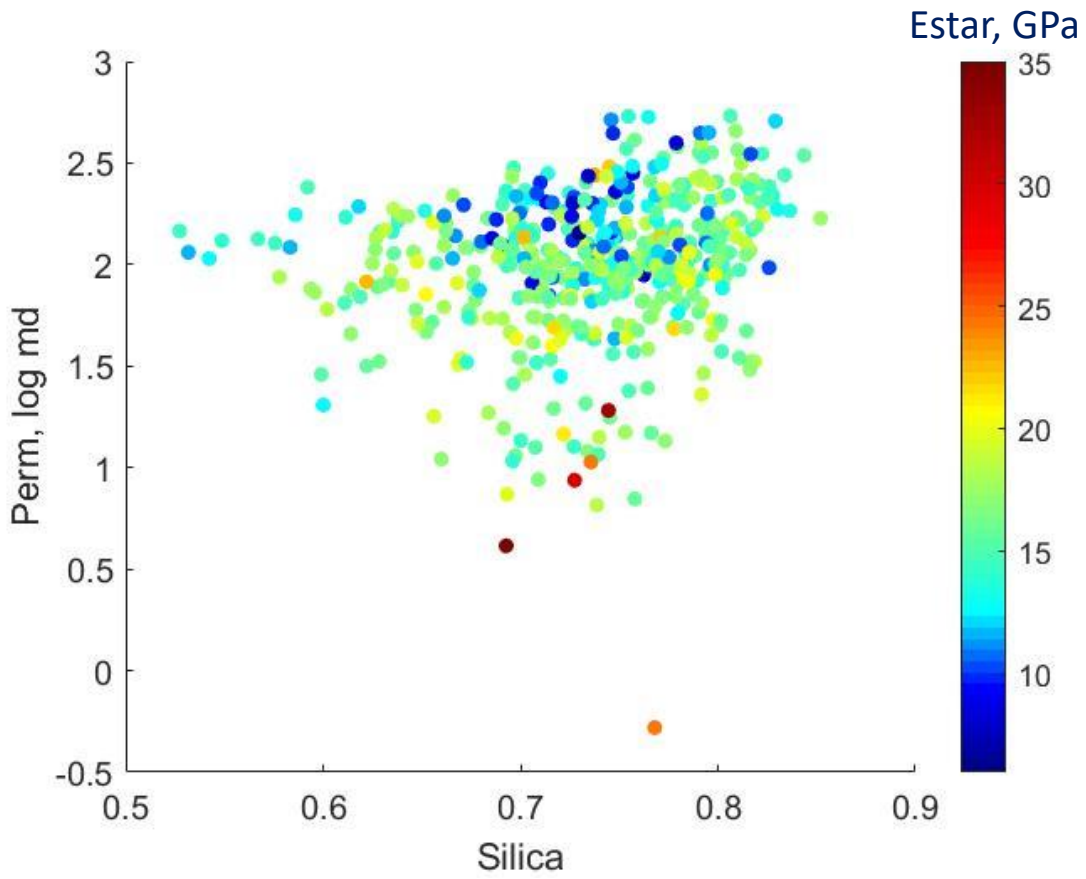
Capturing Data Below Wireline Log Resolution

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.

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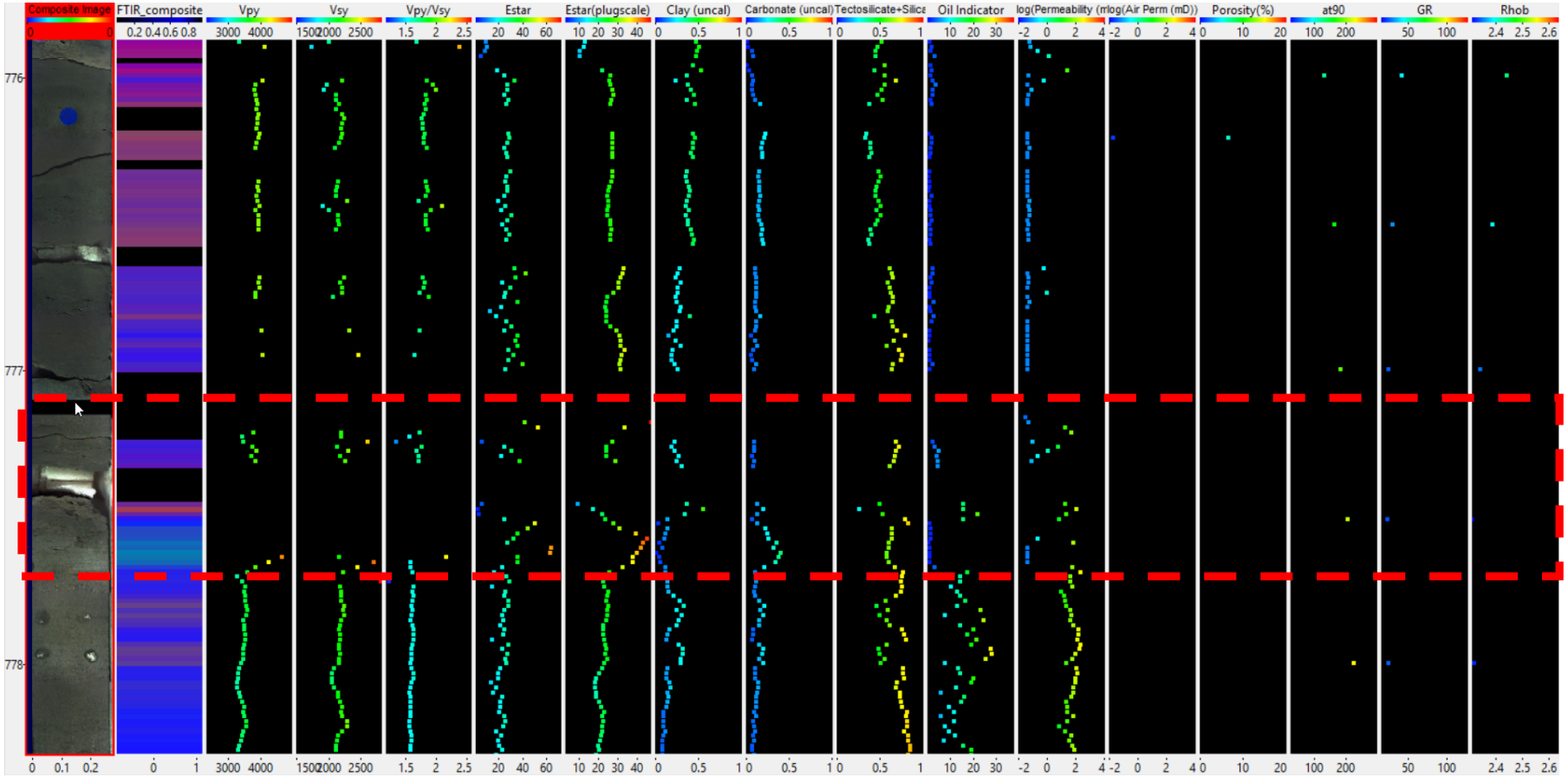
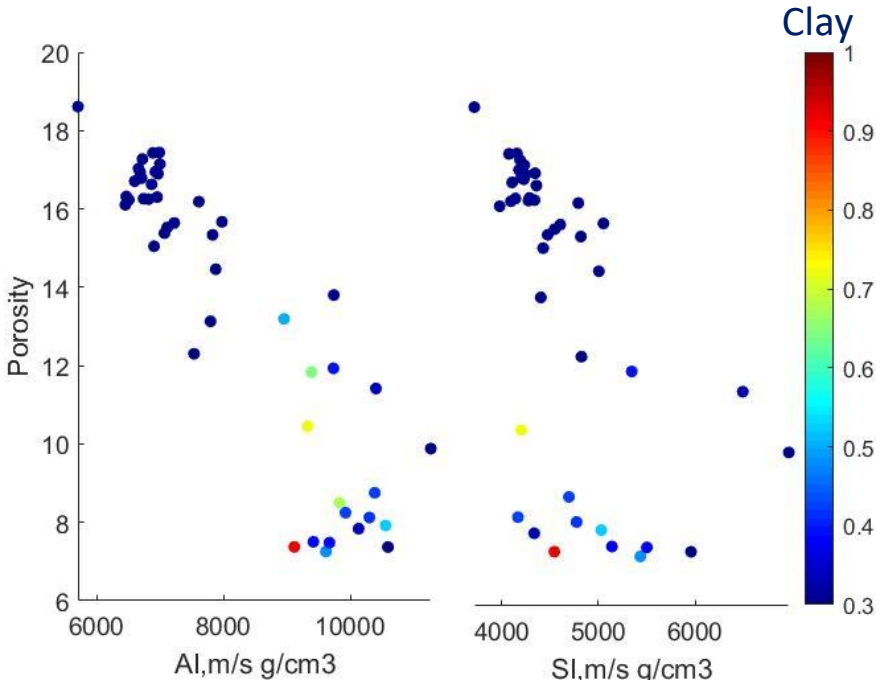
Identifying Max Flooding Surface from AutoScan

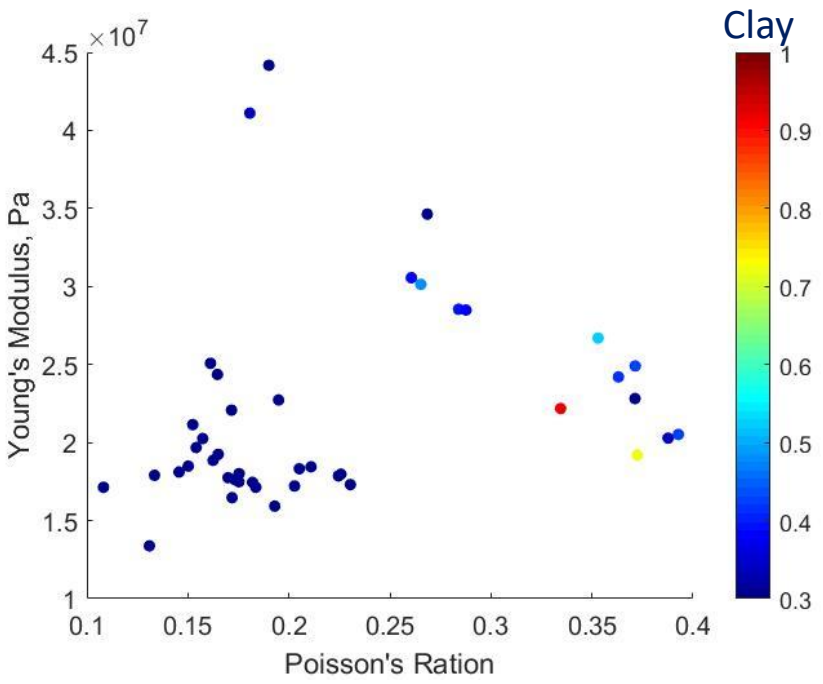
Well-defined flooding surface at ~777 feet. The zone is represented by condensed section.



What's next?

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





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Acknowledgements / Contacts / Questions

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