SPECIAL CORE ANALYSIS in the Digital Age, Challenges, New Insights and Recent Developments.

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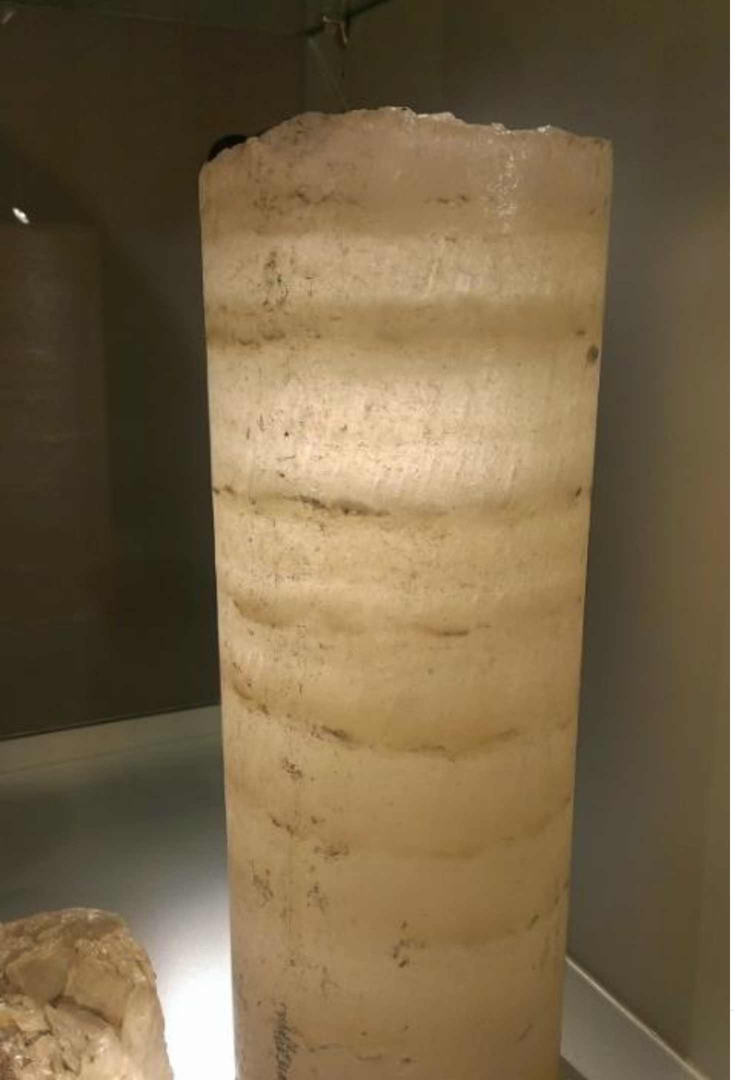
Technical Advisor Core Analysis

SPWLA DOHA 2019



Why we need a Core?

- **Geological and Sedimentological Information**
  (Rock type, Structure,….)
- **Flow Capacity**
  (Permeability)
- **Storage Capacity**
  (Porosity, Reserves/ Hydrocarbon Saturation)
- **Log Calibration Data**
  (Sw, Archie's parameters, FRF, FRI and m & n)
- **Multi Phase Flow and Capillary Properties**
  (Relative Permeability, Capillary Pressure, Wettability)
- **Geo-Mechanical Properties**
  (Rock and Pore volume Compressibility)

Core Analysis Main Objectives

- Obtain rock material and fluids which are representative of the reservoir formation.

- Minimize physical and chemical alteration of the core during coring, core handling and preparation (e.g. cleaning/drying).

- Perform core analysis experiment and measure rock petrophysical properties using representative reservoir core material, fluids and conditions.

Core Analysis - The One Million $Dollar Question?

Is the Core Material **Representative**

of the Subsurface Reservoir or **Altered?**

Changes in the core and fluids content during coring are **unavoidable**, but alteration can be **minimized**.

Damage is an **Irreversible process** (e.g. fractures, clays structure collapse, mineral dissolution, deformation,…)

Alteration is a **Reversible process** (e.g. fluids saturation, wettability restoration, pressure & temperature,…)

Core State General Considerations

Fresh or Preserved State Core:

- **Mud Filtrate/Additives Invasion** during coring (**mud tracers**, type of mud, overbalance, remobilization of immobile fluid phases, fines,….).
- **Pressure and Temperature Reduction**, Gas expansion (precipitation of asphaltenes, waxes, heavy HC,….).
- **Core Handling** exposure to air and evaporation (oxidation, precipitation, dehydration,…), transportation.
- Changes in minerals (e.g. clays, critical minerals) electrochemical characteristics and equilibrium.

Cleaned-Restored State Core:

- Cleaning process efficiency and minerals structure damage
- Aging methodology, aging oil type (STO, live,…) and time.
- Reservoir geological, geochemical and saturation history unknown and complexity.
- Saturation hysteresis effects and fluids compositional changes vs. geological time.

Pre-Study Approach in Core Analysis

Proper pre-investigation of rock mineralogy and structure prior to core preparation

- Critical Clays, sensitive minerals using XRD, SEM, THS Petrography, IR Spectroscopy.

Wettability Control

- Wettability consideration, mud invasion, wettability state after core cleaning and restoration.

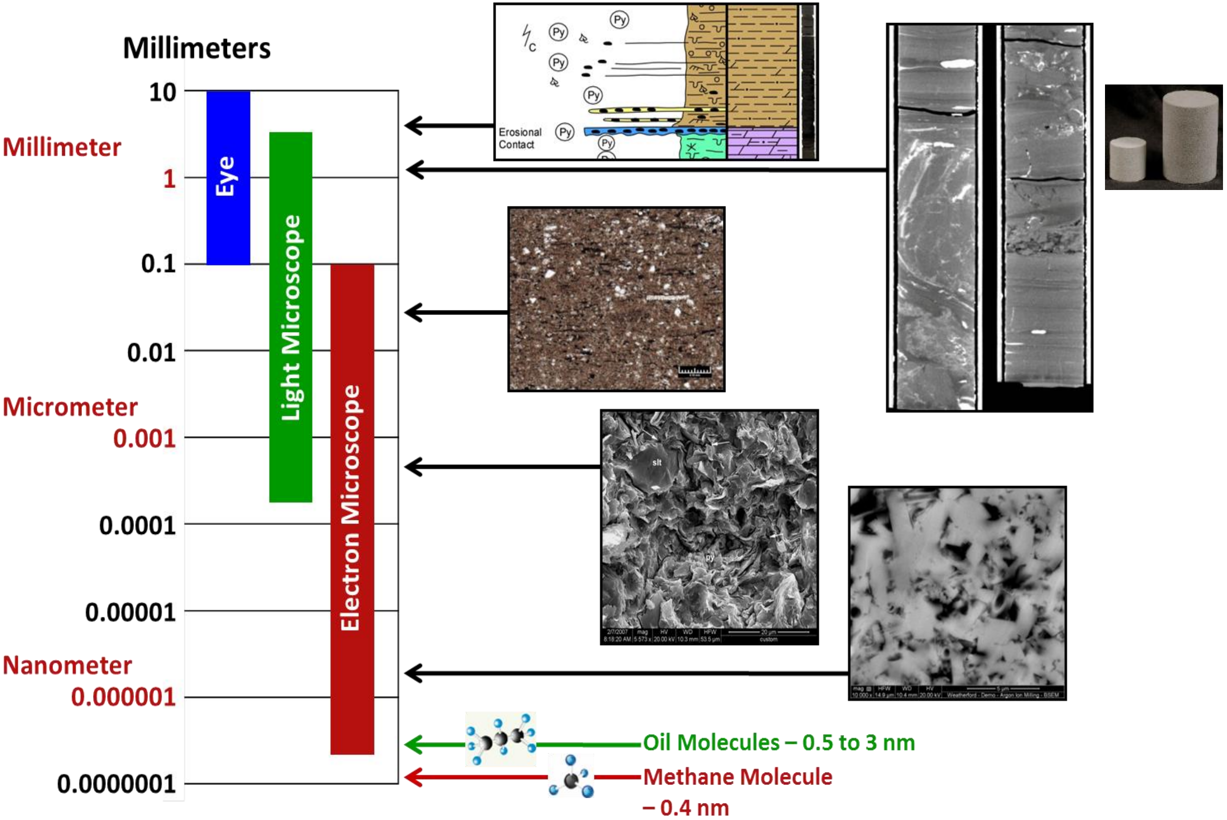
Fluids Properties and Composition

- Formation Water Salinity, pH and Composition, crude oil composition, asphaltenes, mud contamination.

Rock Minerals and Fluids Interaction

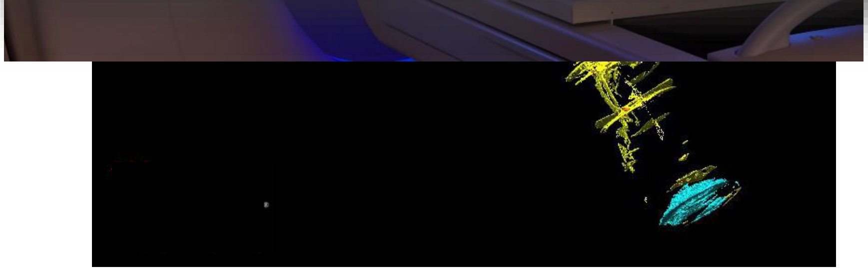
- Brine sensitivity studies, critical velocity/fines migration, salts precipitation.

Scale of Inspection - Rock Types

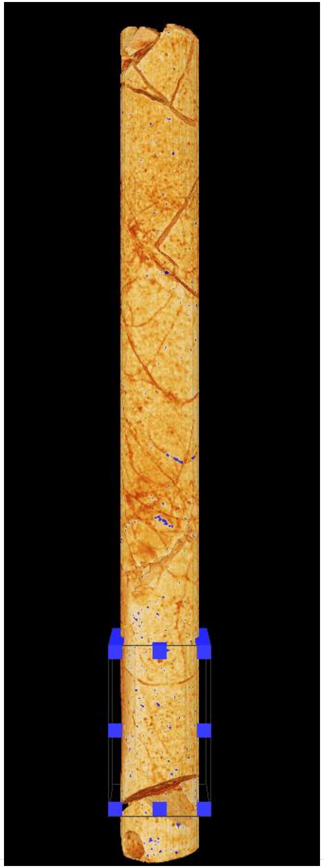


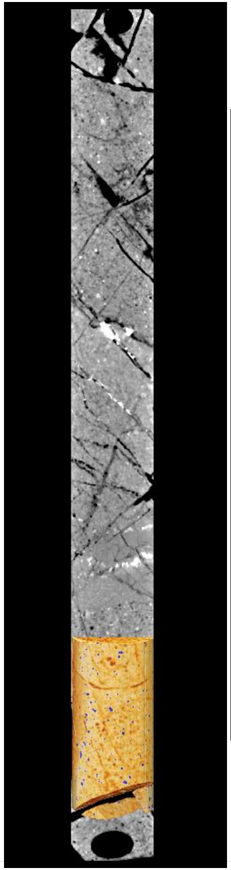
Improvements and Applications – 3D Dual Energy CT

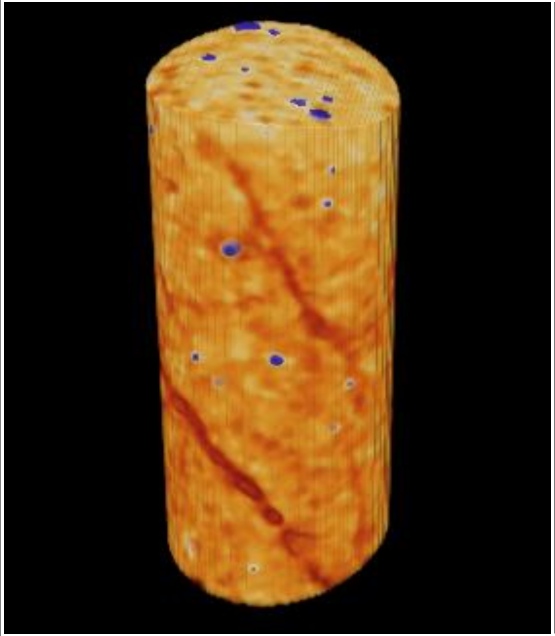
- **SPEED** – can scan 4.0cm of core with each rotation; provides 25% faster scan times provides imaging at 2 different energies; ultra-fast reconstruction module.
- **QUALITY** – CT Protocols designed specifically for Core Analysis, **improved resolution and reduced image artifacts** such as beam-hardening and high density streaking (Artifact Reduction Algorithm).
- **Benefits of Dual Energy CT (DECT):** calculates **bulk density (RHOB)** and PEF at 0.3 mm (Zeff atomic number/composition); screens core for **major mineral components, organic material, and porosity**; categorizes lithofacies.

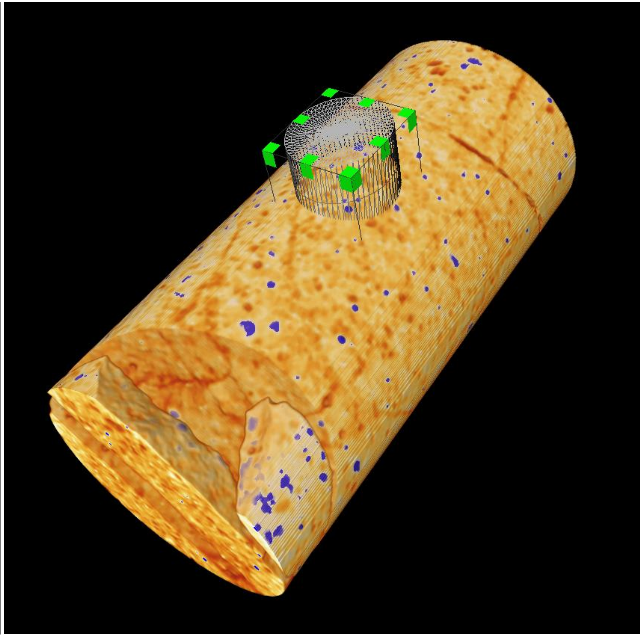


CT Scan Virtual Seal Peels Selection and Plugging

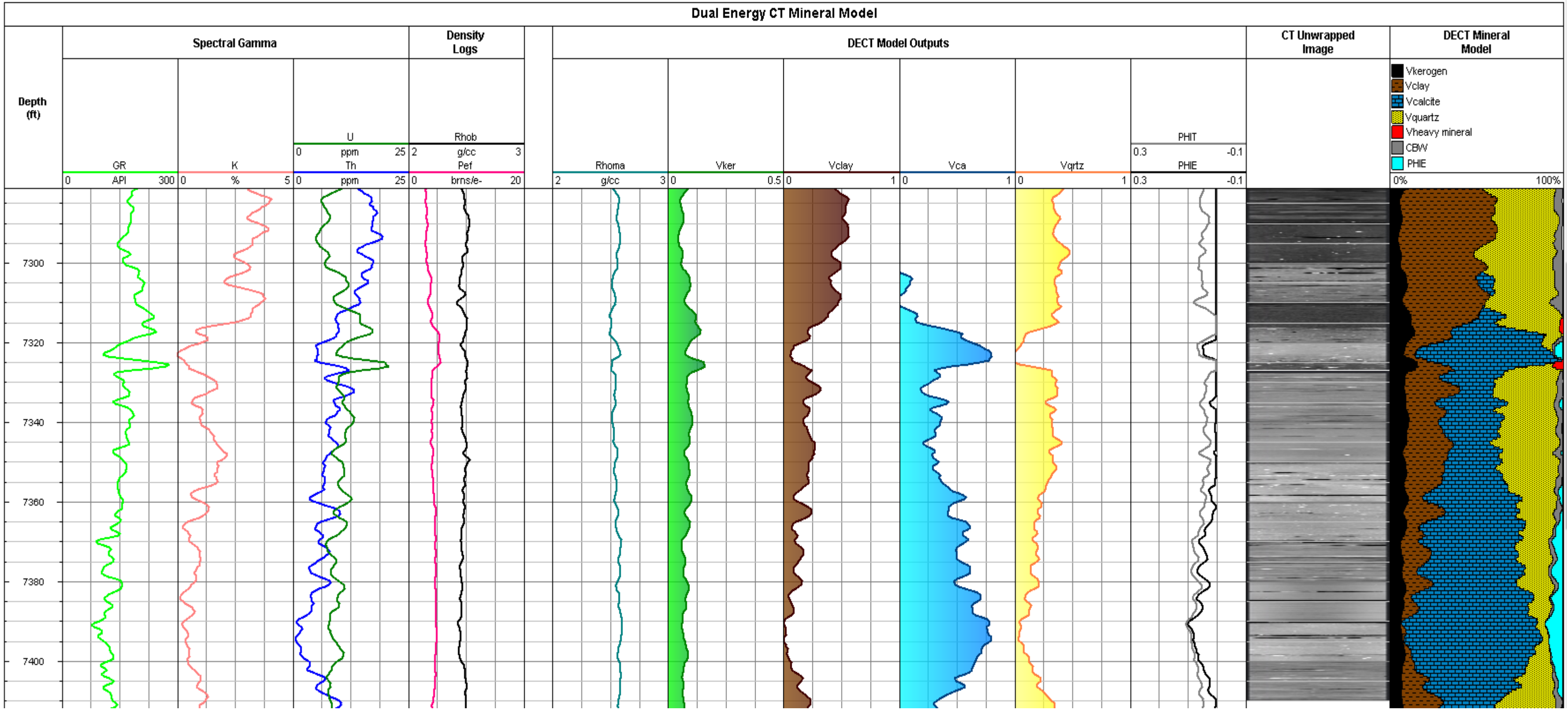








Dual Energy CT Lithofacies/ Mineralogy Log



DECT vs. Wireline and BHI Logs

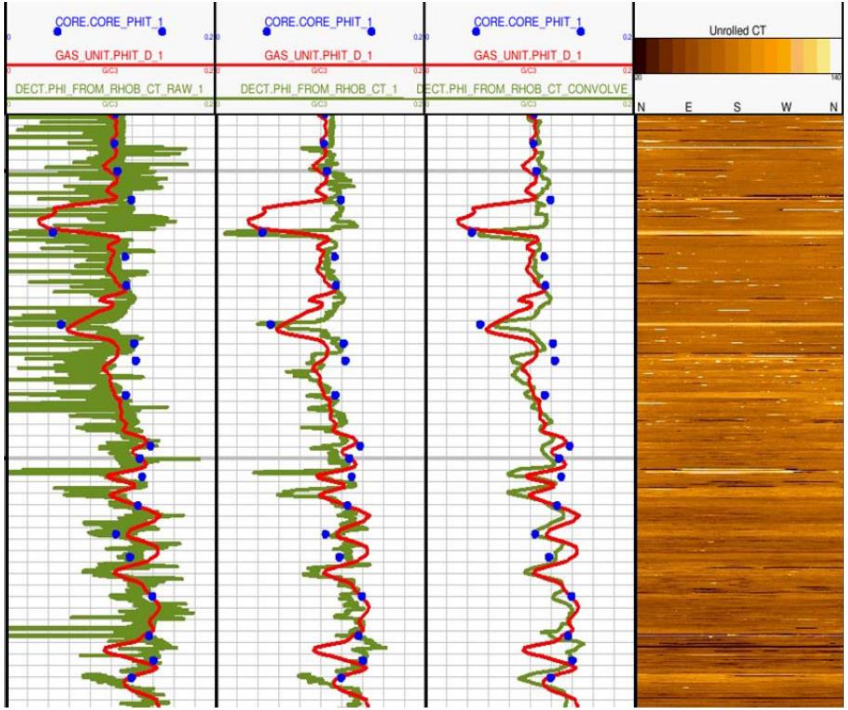


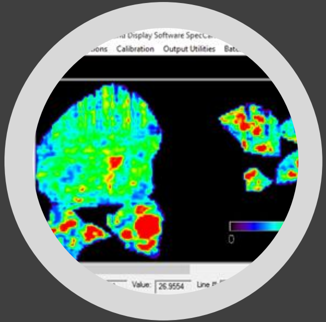
Figure 6: Total porosity from wireline log (red), from DECT (green) and core measurement (blue) over more than 100 feet of investigated interval. First column is with raw DECT data, second is with smoothed and filtered DECT data and third column is with DECT data averaged to same resolution as the wireline density tool (0.5m). The fourth column is the corresponding unrolled surface of the imaged core.

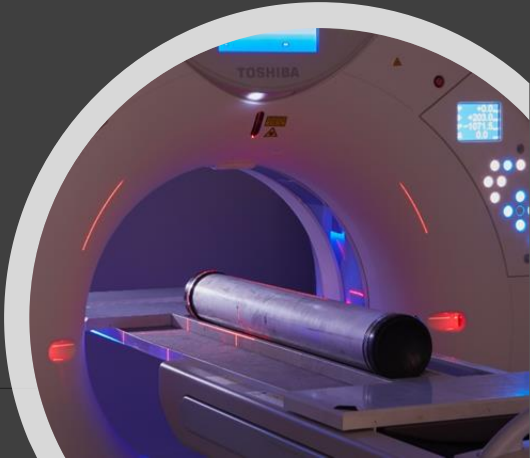
Ref.: SCA 2016-031, O. Lopez et al.

: 2 meter section of QuantaGeo © borehole imager (left) and corresponding unrolled CT surface of the two 1 meter cores (right) aligned and oriented using VirtualCore software.

Laboratory Measurements Integration

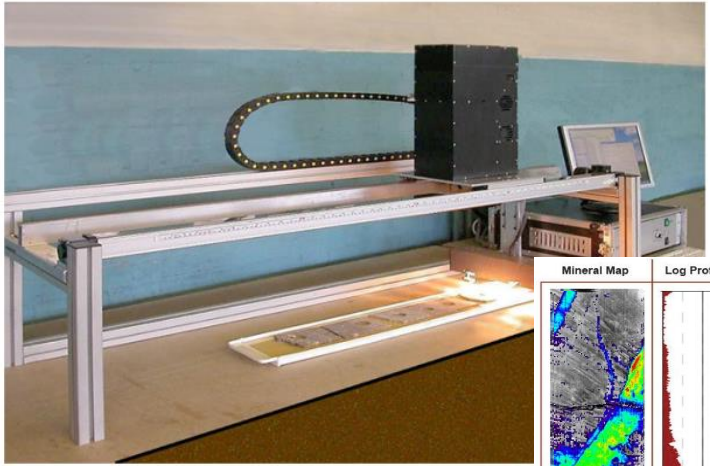
- **DUAL ENERGY 3D CT SCAN**
  - Sedimentary Features, Density, Porosity
  - 3D and Unwrapped Core Images
  - PEF and Atomic no. mineral analysis
  - Fractures and Structural Analysis
- **INFRARED, UV SPECTROSCOPY and QEMSCAN**
  - Facies and Stratigraphic Mapping
  - Mineralogy Log (clays, carbonates,…)
  - HC and Mud invasion quantification/typing
- **CORE SCRATCH**
  - UCS Log and Strength Profile and Mapping
  - Acoustic Probe Sonic Measurements
  - Laser Topography

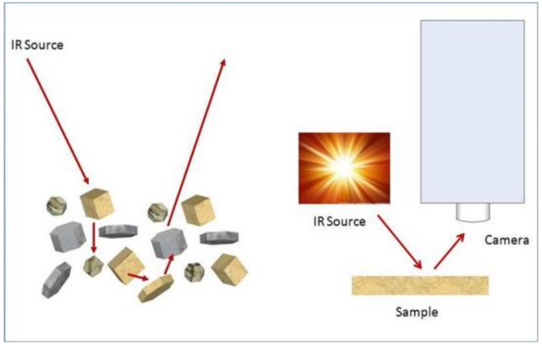


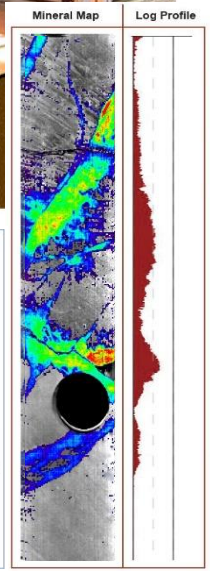


Infrared Spectroscopy Mineral Analysis

- **Core, cuttings & plug mineral logs**
- **Facies and Stratigraphic mapping**
- **Clay & Carbonate mineralogy**
  - Quantify each clay type, derive Total Clay
  - Differentiate Dolomite, Calcite, Aragonite and Siderite
- Wireline Calibration

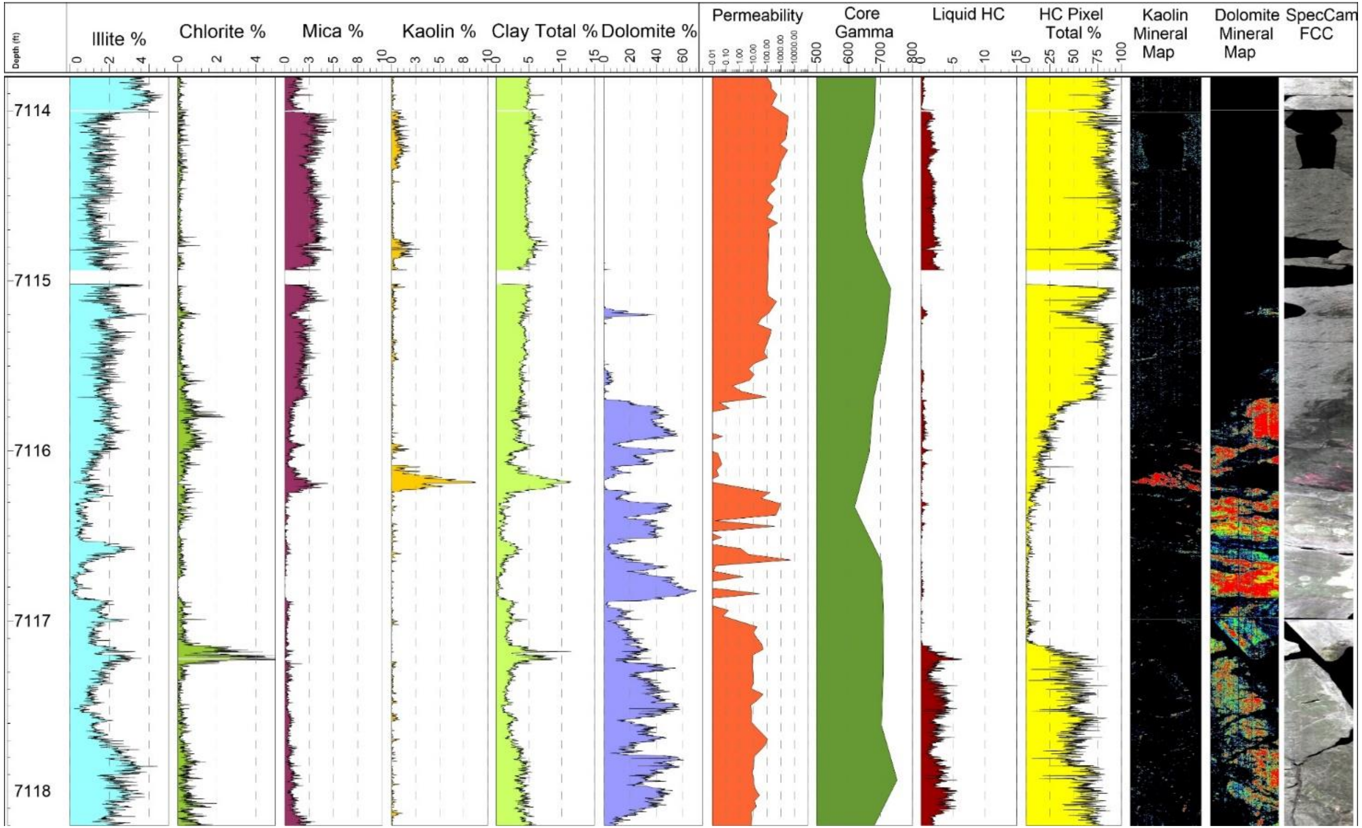






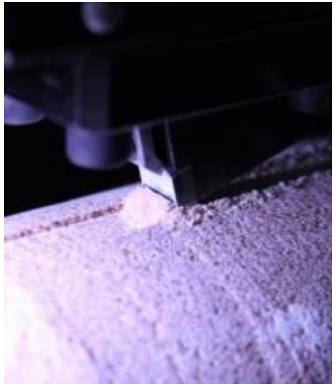
Left: a 1 metre section of drill core. Image on the left highlights distribution and grade of a key mineral on a grey scale IR image background

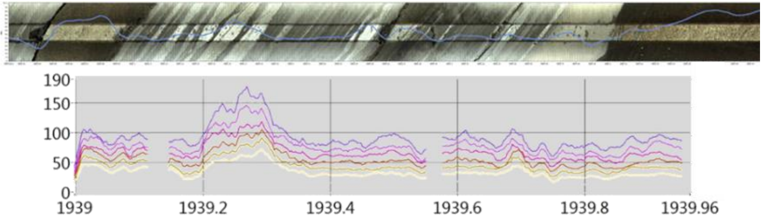
IR Mineralogy vs. Core Analysis



Core Scratch - Principle

TRACE A GROOVE ON SURFACE OF ROCK SAMPLE





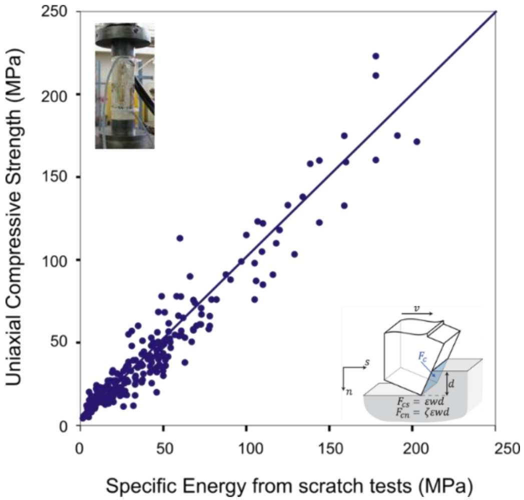
work performed by cutter

$$W = \varepsilon \times V$$

strength

volume of rock cut

A DIRECT MEASURE OF UCS WITH NO CALIBRATION

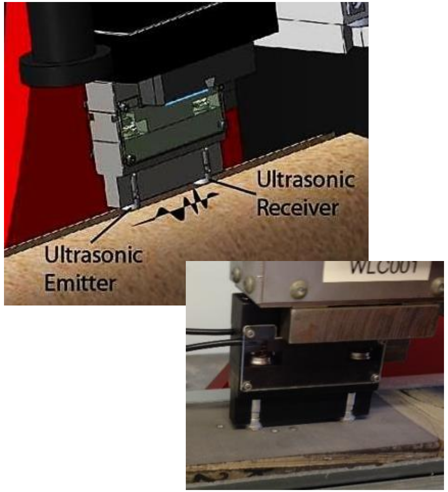


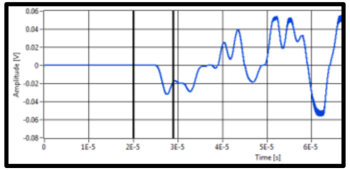
92 sandstones, 86 limestones, 19 shales, 6 dolomites, 4 chalks, 3 granites, 2 coals, 2 anhydrites

5 INDEPENDENT LABORATORIES (1996 – 2012) TOTAL (FRANCE), UNIVERSITY OF MINNESOTA (USA), UNIVERSITY OF MONS (BELGIUM), IKU-SINTEF (NORWAY), EPSLOG (BELGIUM)

Core Scratch - Ultrasonic

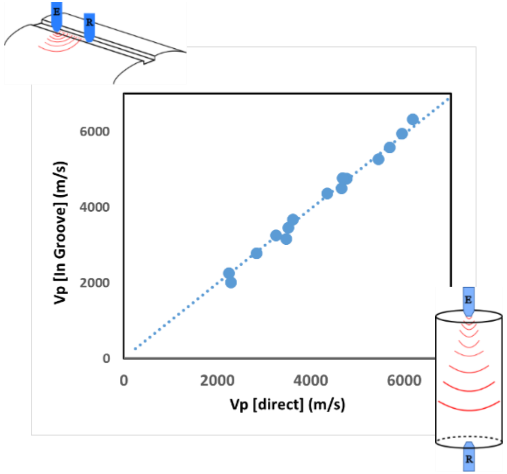
AUTOMATED ULTRASONIC MEASUREMENT ON SURFACE LEFT BY SCRATCH

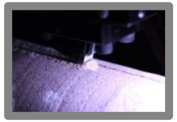


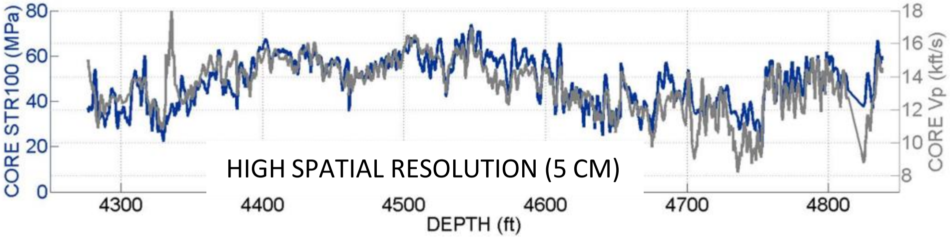


Δt

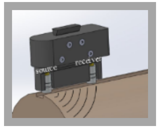
$$V_{p,s} = \frac{L(= 4\ cm)}{\Delta t_{p,s}}$$





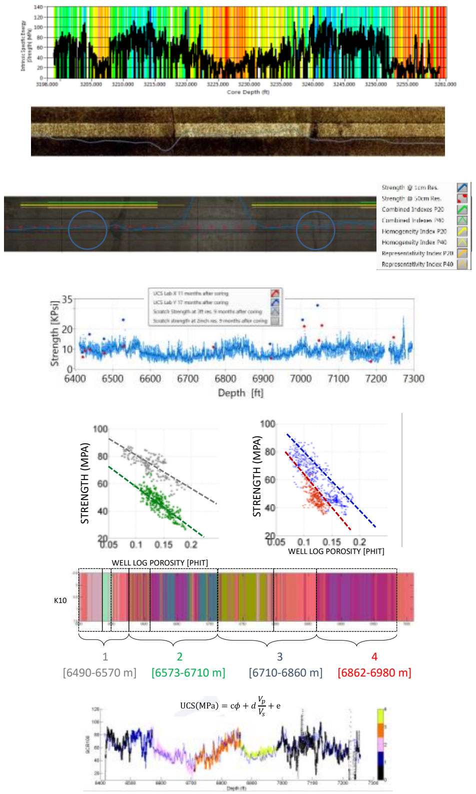


HIGH SPATIAL RESOLUTION (5 CM)



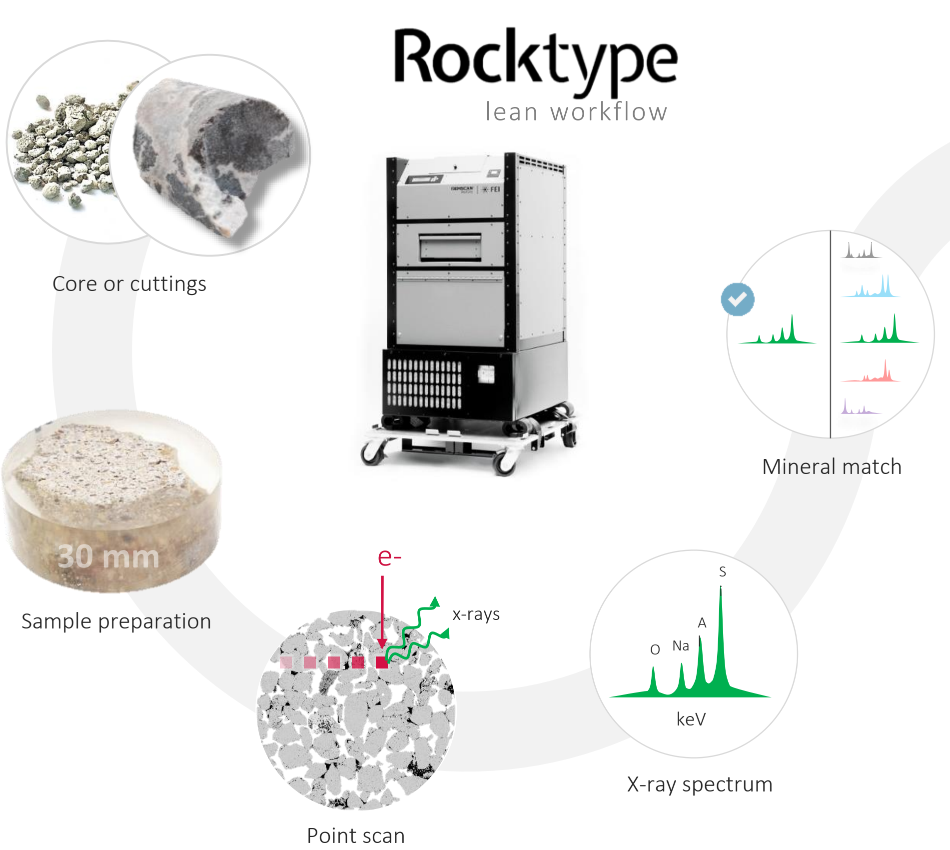
Core Scratch - Applications

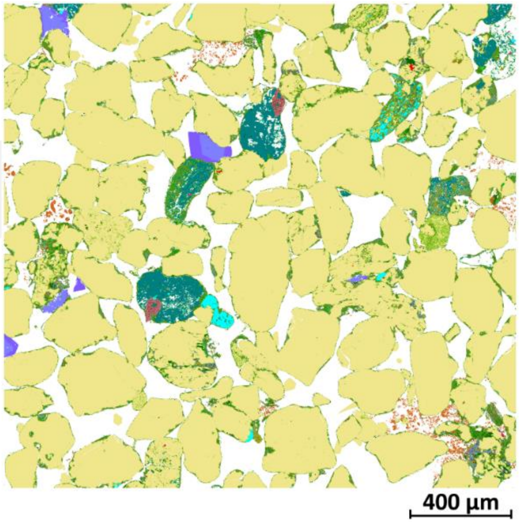
- Core heterogeneity mapping
- Continuous porosity profile
- Grain size distribution analysis
- Strategy for samples selection
- Facies Identification
- Strength proxies and integration with wireline data



Geomechanical Facies are colored. Blue line is scratch test strength

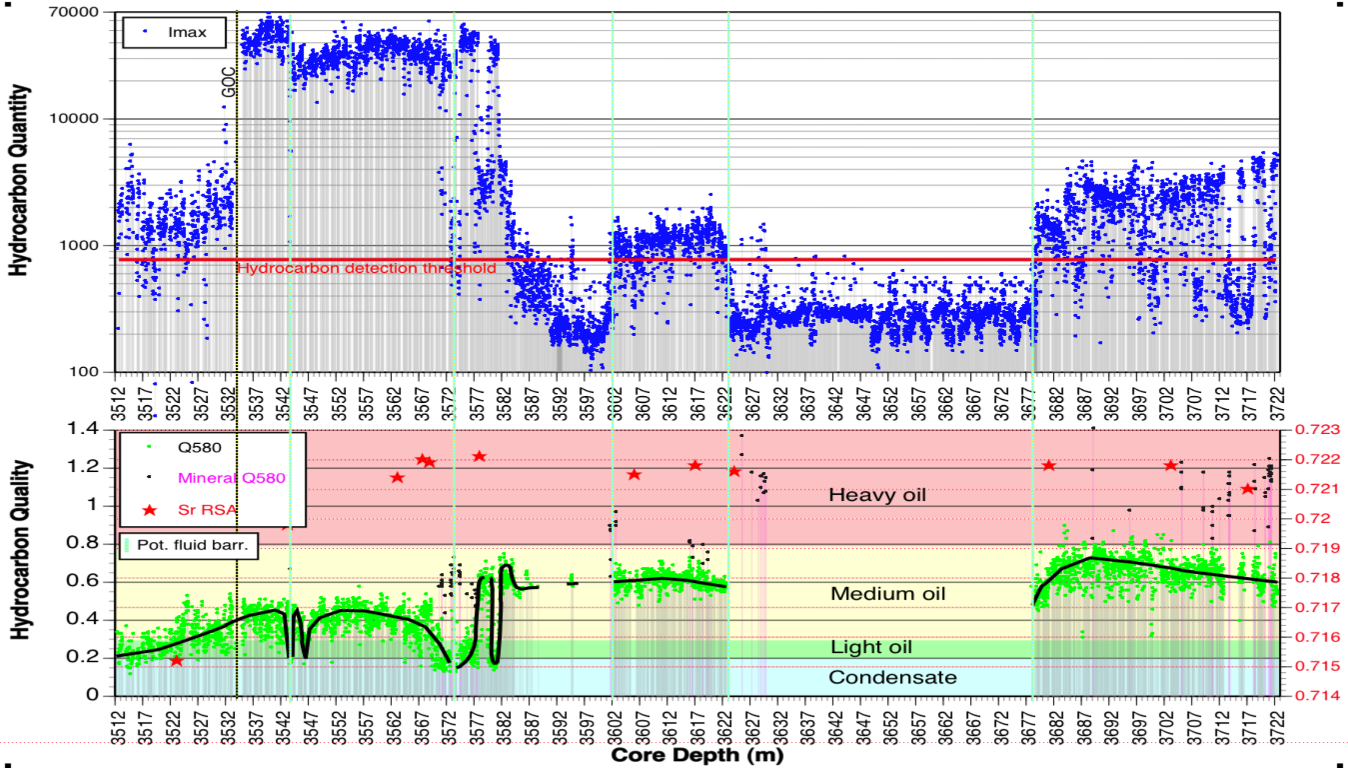
QEMSCAN Petrography





QEMSCAN is a trademark of Thermo Scientific

Principles of HCS™
Fluorescence Emission Spectroscopy

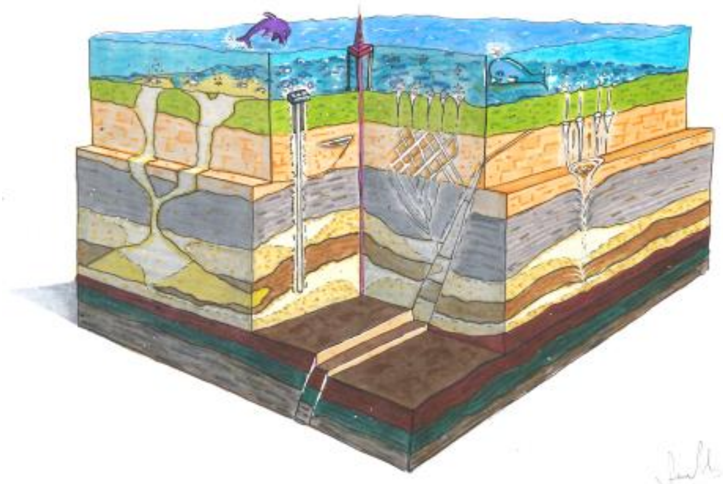


Sr Residual Salt Analysis (SrRSA) to assess fluid communication in the reservoir

$^{87}Sr/^{86}Sr$ - Isotopic approach

Resolve uncertainties related to:

- Mixing of formation water from different sources
- Reservoir compartmentalization
- Hydraulic fracture evaluation
- Reservoir Fluid communication
- Seal quality
- Filling and saturation history

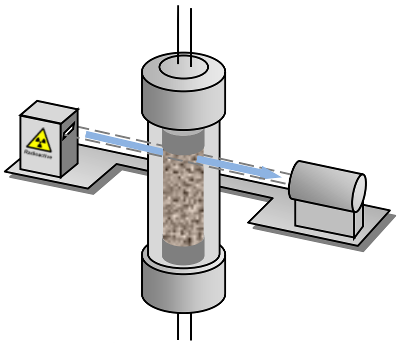


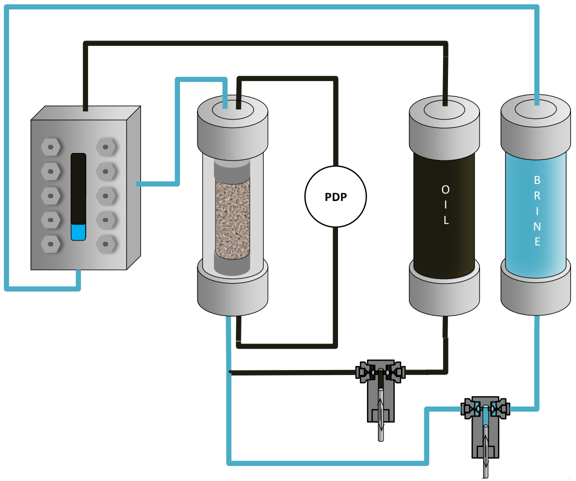
Advanced Flooding Experiments at Full Reservoir Conditions on Whole Core samples using Live Fluids and In Situ Saturation Monitoring.

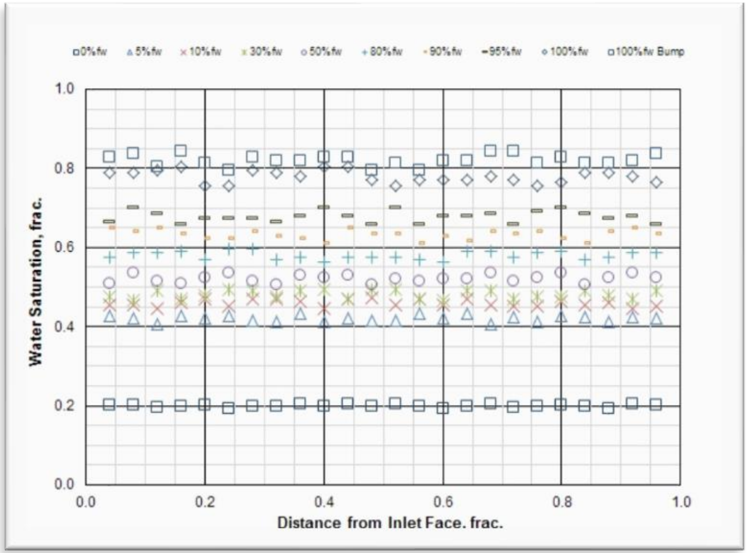
Tendency to perform Special Core Analysis experiment as close as possible to **Subsurface Conditions** to improve results representativeness, which also lead to an increase of experiment complexity, risks, time and costs.

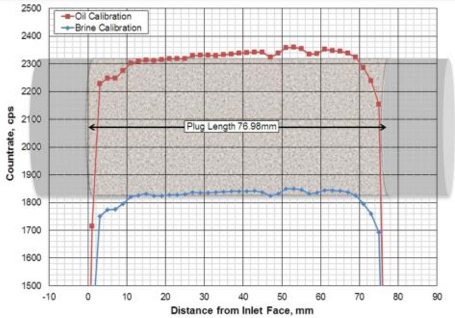
Improvements in **data monitoring, visualization, design and simulation software** for special core analysis, mainly driven by enhanced computational capability.

Relative Permeability with In-Situ Saturation Monitoring



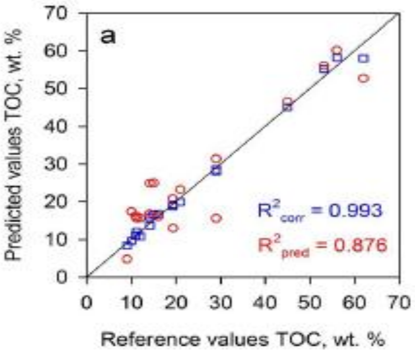


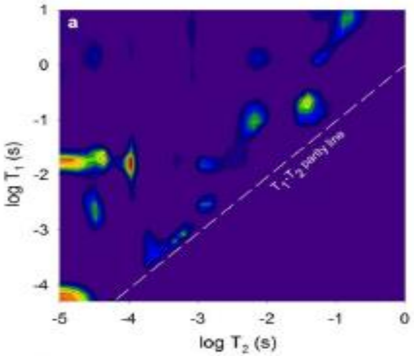


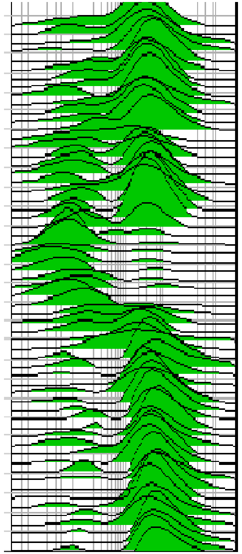


Nuclear Magnetic Resonance Development

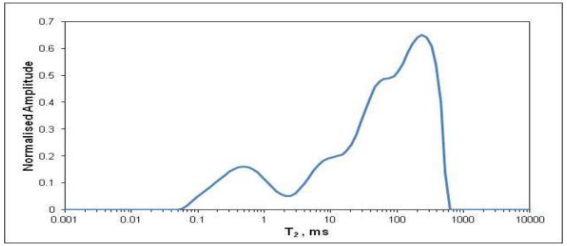
- NMR as Calibration for Logs
- NMR as a Rock Characterization Tool
- **NMR vs. Wettability**
- NMR vs. Clay Bound Water and Qv
- NMR vs. TOC (Gas Shale)
- NMR vs. Mud Invasion in cores







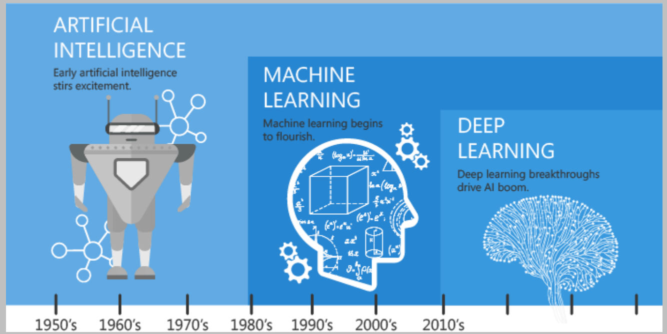
$$\frac{1}{T_{1,2}} = \frac{1}{T_{1,2Bulk}} + \rho_{1,2}\frac{S}{V}$$

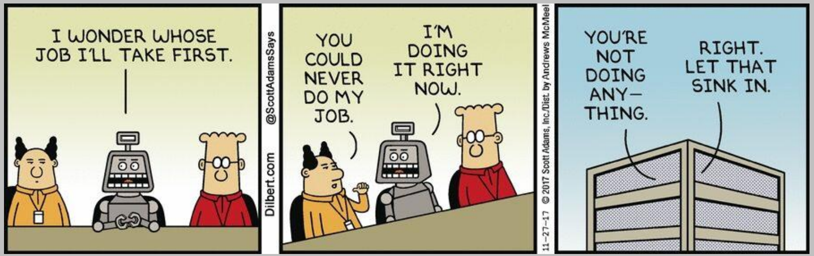


Artificial Intelligence?

Machine Learning Advantages

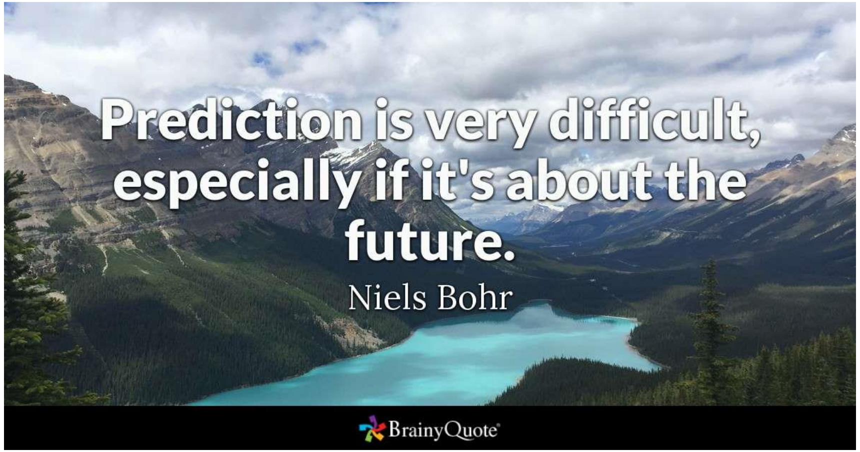
- **No existing rule/equation:** investigate missing possible relationship e.g. upscaling issue Core vs. Reservoir permeability…..
- **Complex rules and equations:** rules and assumptions are too complex to be analysed or relationships are changing (e.g. carbonate vs. sandstone reservoirs).
- **Nature of the data keep changing:** nature of rock data is complex (e.g. Wettability) ML can handle non linear behavior and dynamic mapping.
- **Large amount of data:** ML provide unbiased data approach for large dataset.





Machine Learning Limitations and Challenges

- **Big Data is needed:** most of the large enough existing core analysis dataset are historical. Equipment and methodologies can be different and poor documented.
- **Poor quality data:** Spend time on data quality validation and choose the right data features. Most of core analysis data are still measured, processed and evaluated by human expertise…
- **Expertise is still required:** Historical core analysis dataset are difficult to evaluate and quality assurance can be challenging.
- **Focus on pattern recognition rather than the physics behind the problem:** collaboration between SCAL specialist and ML expert is paramount…. avoid black boxes.



Machine learning can't get something from nothing…
what it does is get more from less."
Dr. Pedro Domingo, University of Washington

Norwegian Cuttings Digitalization Project

The main goal for the project is to use released exploration and appraisal well data to find more hydrocarbon discoveries and to improve drilling operations.

The project key elements:

Use cuttings to get more information about the geology, mineralogy and rock properties to be able to reduce well cost and define new play types.

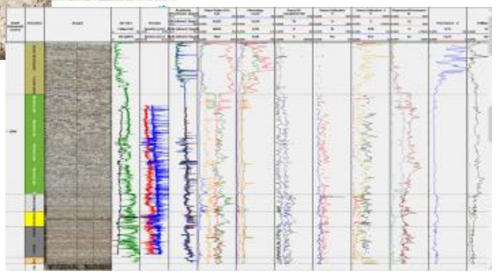
All data to be digital and shareable companies and academia, released through a online digital platform database.

The main goals for the project:

Reduce risk by enabling an interdisciplinary approach, relevant both for subsurface evaluations, drilling and production.

Increase Discovery, Reduced costs = “save” wells.

ROCKWASH GEODATA



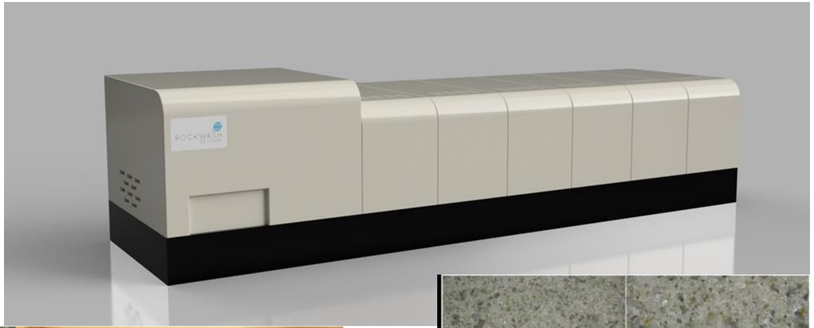
BIG DATA – Norwegian Cuttings Project Database

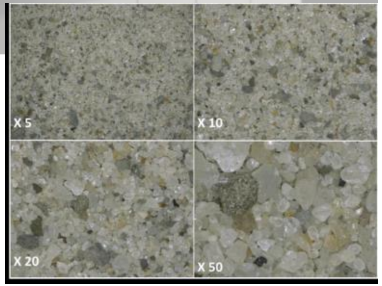
STRATUM RESERVOIR

New frontier for rock digitalization because of full well coverage, large dataset (600,000 cuttings) and standardized and automated analyses approach.

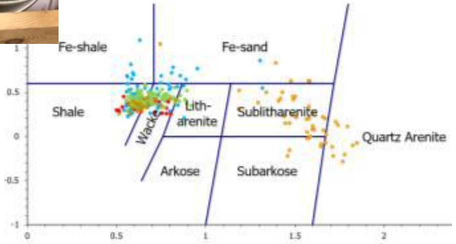
Analyses on 1500 Exploration Wells include:

- Automated Cuttings Washing and Drying
- WL and UV High Resolution Digital Images
- XRF Elemental Analysis
- X-ray Diffraction Mineral Analysis
- QEMSCAN Mineralogy
- IR Imaging Spectroscopy
- TOC Geochemical Measurements
- Cuttings Size Determination by image analysis





ROCKWASH GEODATA



Thank You for your attention!

QUESTIONS?

STRATUM
RESERVOIR