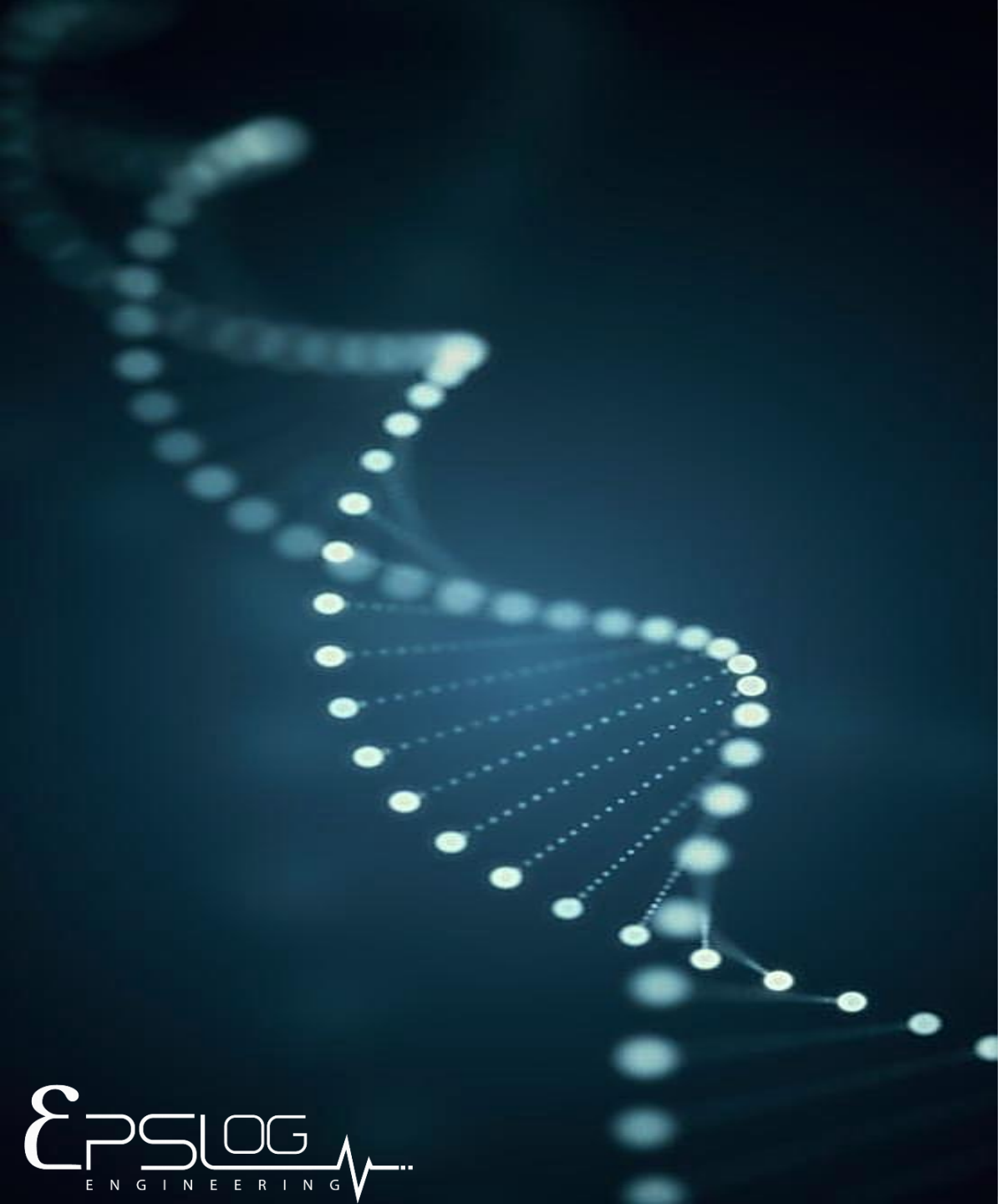


Aberdeen Formation Evaluation Society

Early Trans-disciplinary High Resolution Core Logs to Steer Core Analysis Workflow

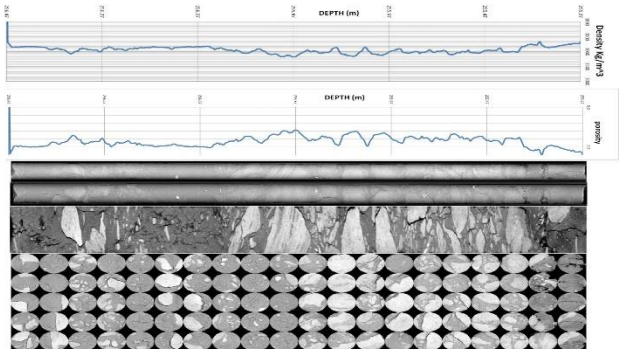
Dr. Christophe Germay
Epslog

CORE ANALYSIS

Standard Worflow

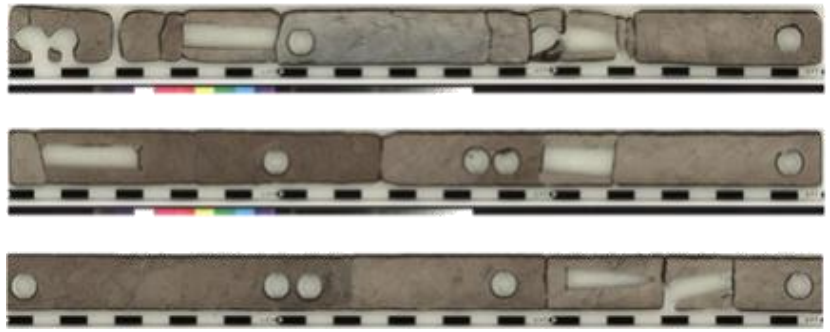
Little is known before causing PERMANENT DAMAGE to your CORES by PLUGGING AND SLABBING…

CT Scan: 3D images
DECT: Density and Atomic Number logs



Core Gamma logs or Spectral Core Gamma logs

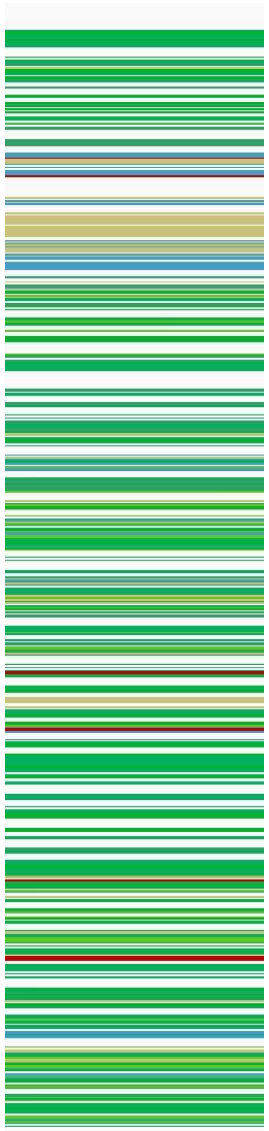
Preserved Sample selection, systematic/specific plugging & slabbing cause permanent damage to the core…



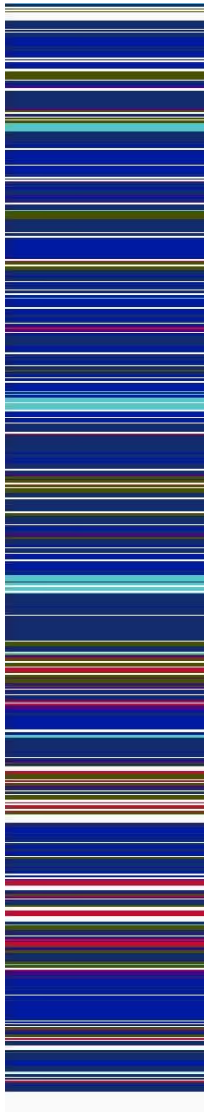
CORE ANALYSIS

Standard Workflow

Core 1: 39.42m
Preserved samples and plugs taken then slabbed



Core 2: 37.29m
Few intervals in bad conditions and fractured



High Resolution Core Logs
Recovery:
Core 1: 61.6%, 24.29m
Core 2: 86.1%, 32.1m

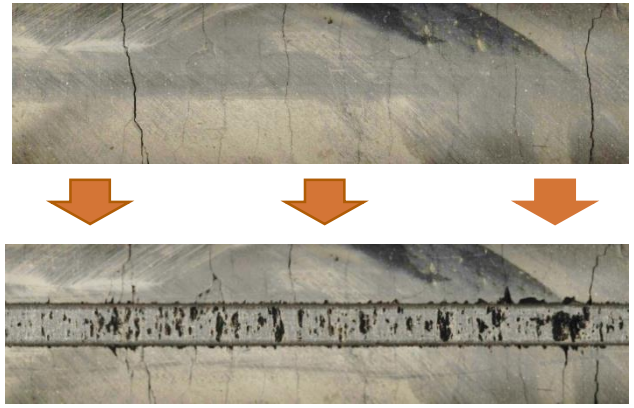
25% percent of permanent Damage & missing data in Core 1

Limited Foot Print

Slabbing and core aging may cause damages when dealing with specific rocks…

DELINEATED SHALE – Ex 1

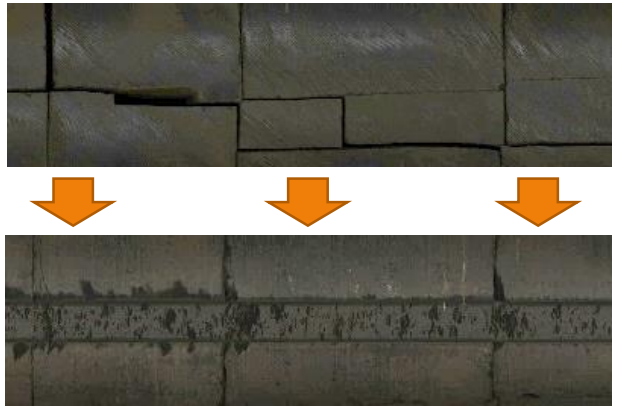
- Transverse fractures
- Delicate core handling
- Improper for plugging



Do not induce further damage to tested core samples

SHALE – Ex 2

- Longitudinal fracture
- Cores unfit for plug sampling

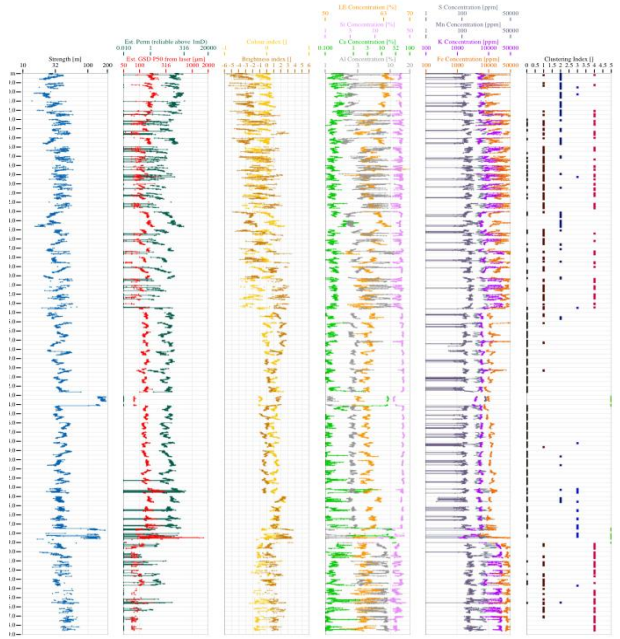


Produce meters of reliable data with centimeter resolution

CORE ANALYSIS

Can we get more prior sampling?

Our motivation is to grasp the complex nature of the cores before plugging and slabbing



How? Rapid high resolution **core logs** to equip core specialists with trans-disciplinary & quantitative core data right after barrel opening

Challenge: before slabbing, **no direct access to suitable surface** to take photography or conduct measurements.

Solution: Disruptive innovation based on the “scratch test” technology to surgically open a window at the surface of the core

Advantages:

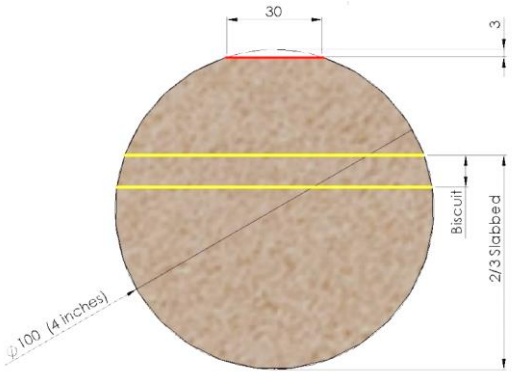
- Dry cut / No water damage;
- Rapid / Limited exposure;
- Data are interpreted live / Direct availability;
- All depth synchronized and data formatted for ML applications / Fast turnaround integration.

Game changer for Core Analysis

Sample preparation

DISRUPTIVE MiniSlab

…the gateway to…



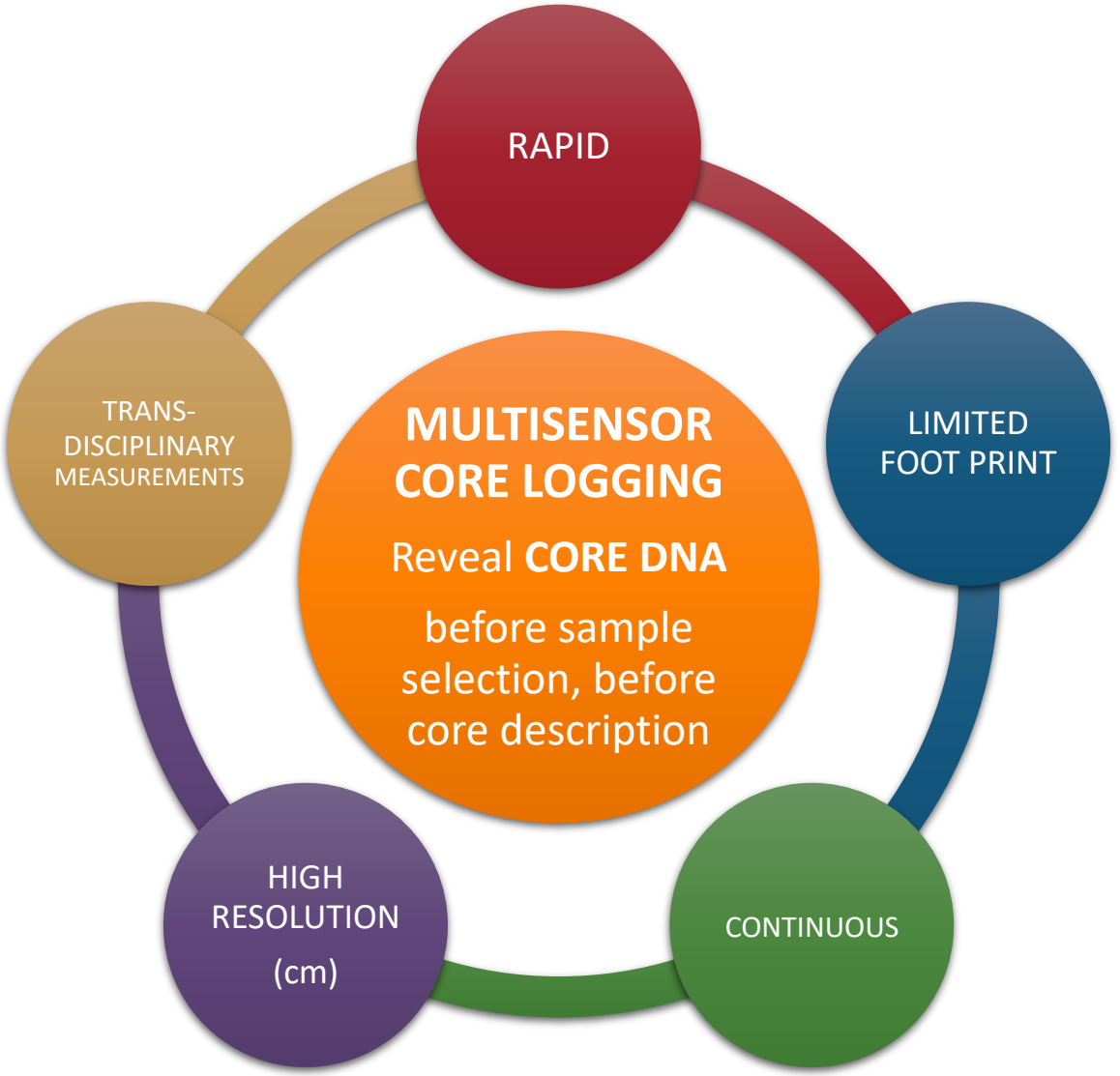
CoreDNA Solution

Smooth flat surface on full cores with PDC cutters

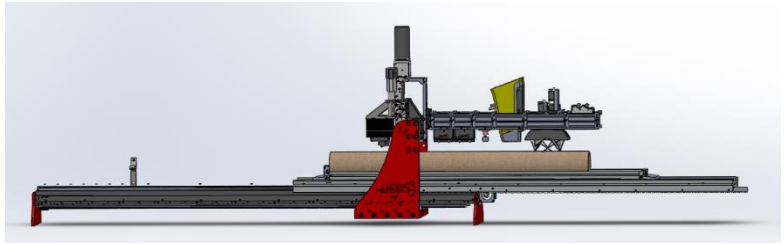
- No prior sample preparation required
- 3 cm large window max, machined by PDC cutters with submillimetric cuts;
- Level @ µm scale;
- Only 3mm thick layer of material removed (on 4 inches diameter core);
- Preserve cores for plugging and slabbing;
- Suitable for a comprehensive series of continuous measurements.

CoreDNA

Common features between the measurements



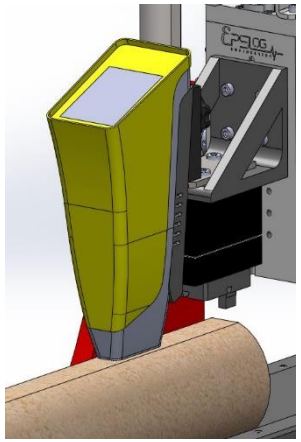
TEST SEQUENCE (4INCHES CORE)



MINISLAB

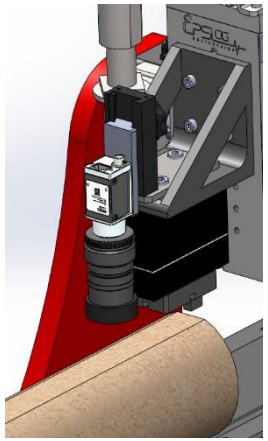
Core logging rate: 3ft per hour, resolution ~1cm

XRF



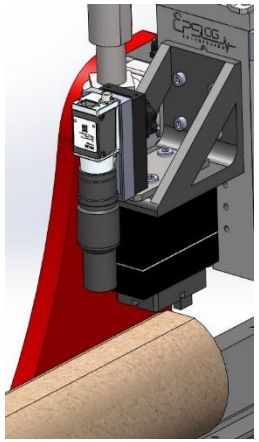
Elemental Composition

HR Photo



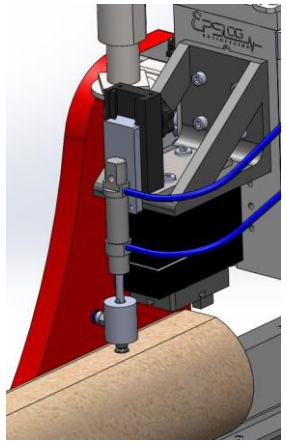
Core photo (Vis & UV) ~35µm/px

UHR Photo



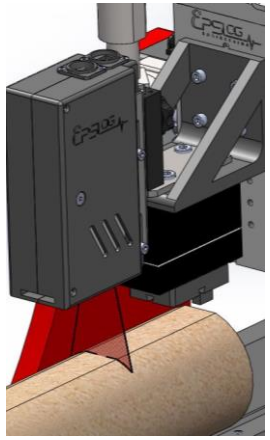
Core photo (Vis & UV) ~1.8µm/px

Probe Perm



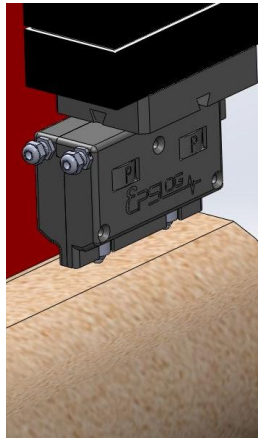
Permeability index

Laser Scan



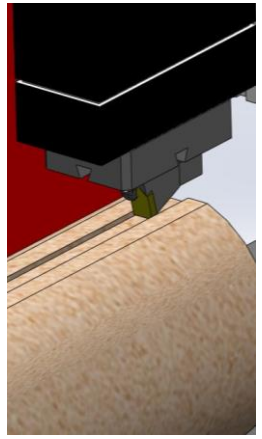
Grain size index

Ultrasonic Vp&Vs



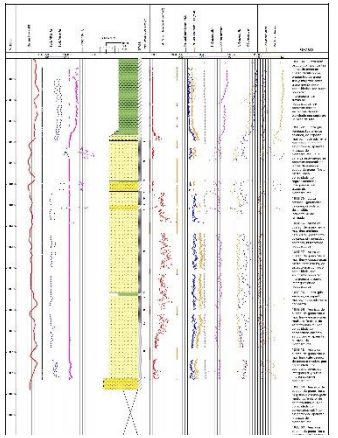
Sonic Logs

Strength



UCS

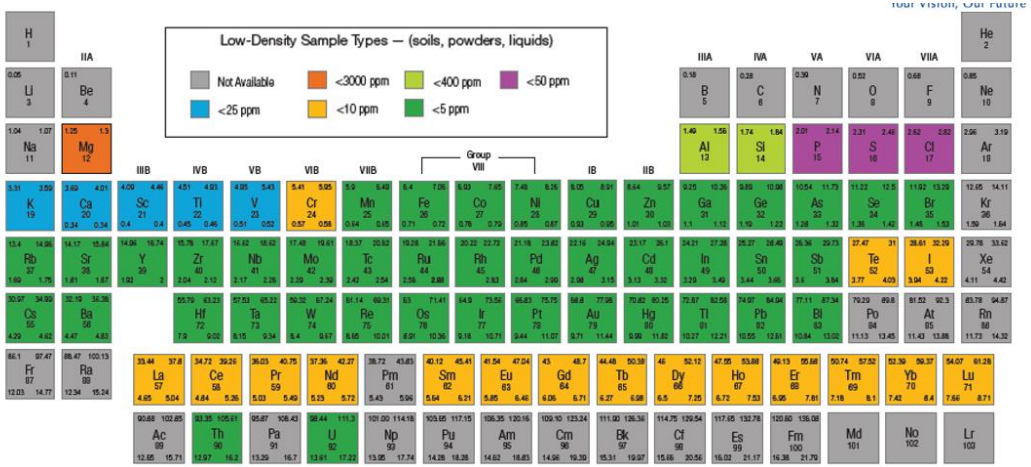
Sedimentology description



pXRF – Geochemistry logs

Continuous elemental composition (XRF):

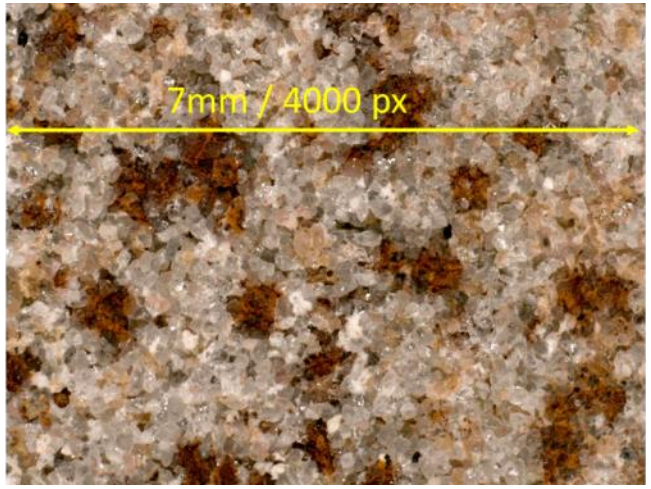
- Spot size (spatial resolution): 1cm;
- Measurement time: ~20s;
- Element from Mg and above;



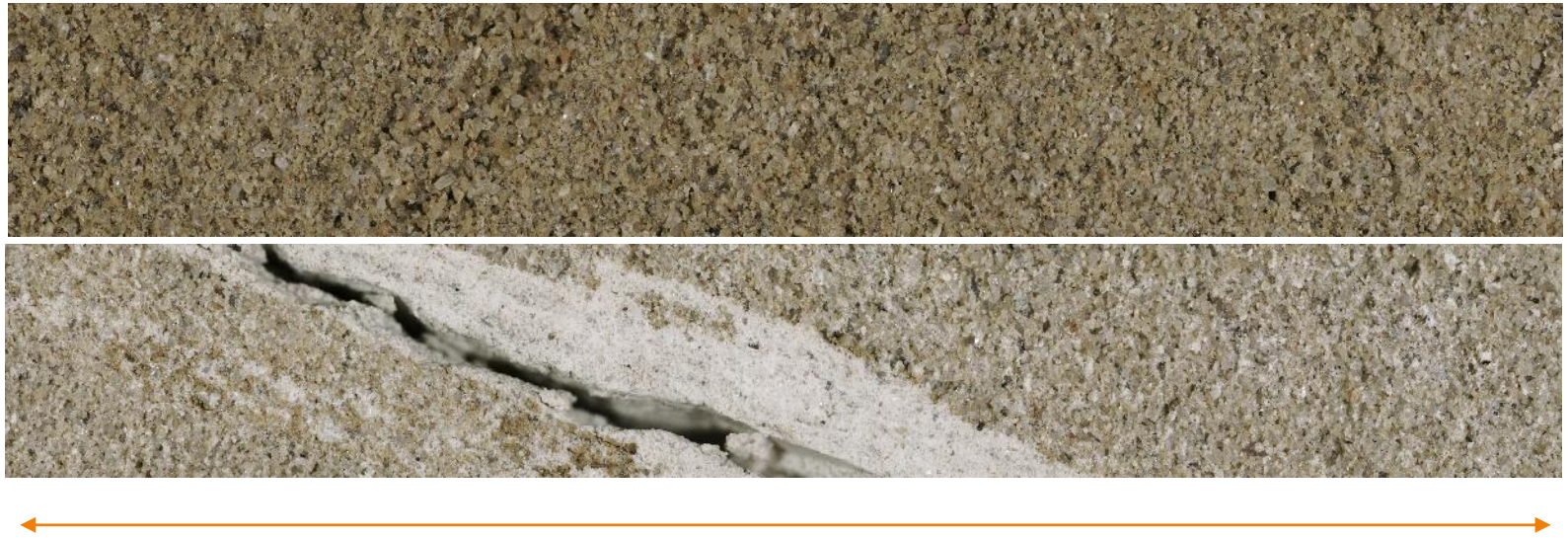
- Extend core logging data set with geochemistry profiles (mineralogical information) to produce a more complete lithofacies description very early in the core analysis workflow.

HIGH RESOLUTION CORE PHOTOGRAPHY

- VISIBLE LIGHT & UV LIGHT
- 1.8µm PER PIXEL
- MADE ON DRY CUT (NO FLUID DISPLACEMENT)
- EARLY IN THE WORKFLOW



Continuous “thin section” profile

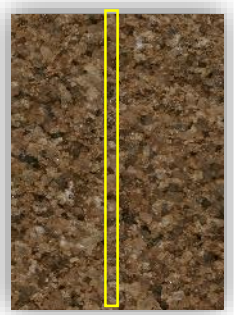


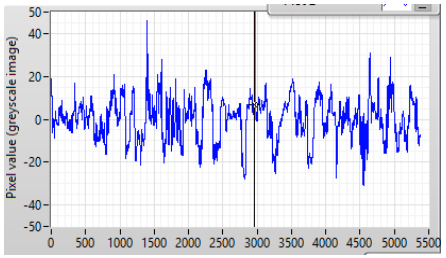
7mm

5cm

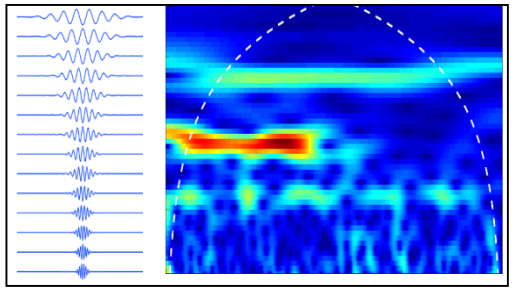
Sandstone 1
Sandstone 2
Carbonate 1
Carbonate 2

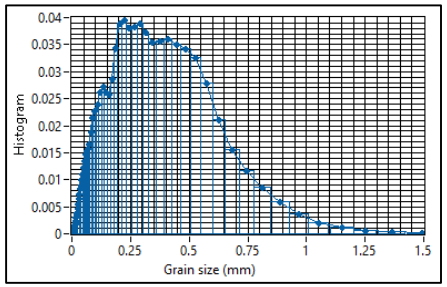
GSD INDEX PROFILE

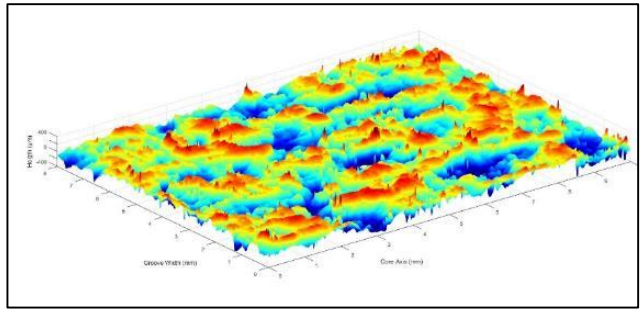


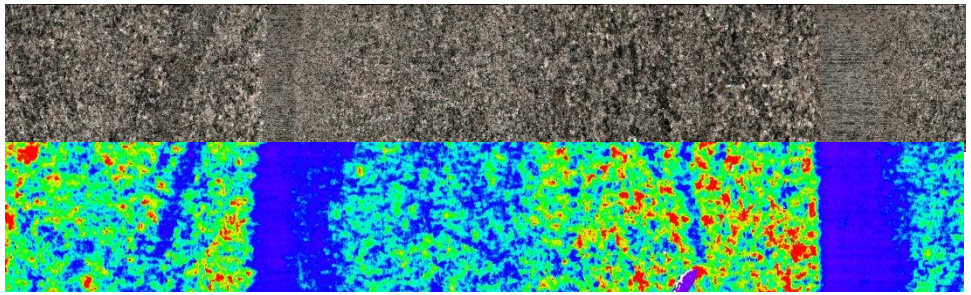


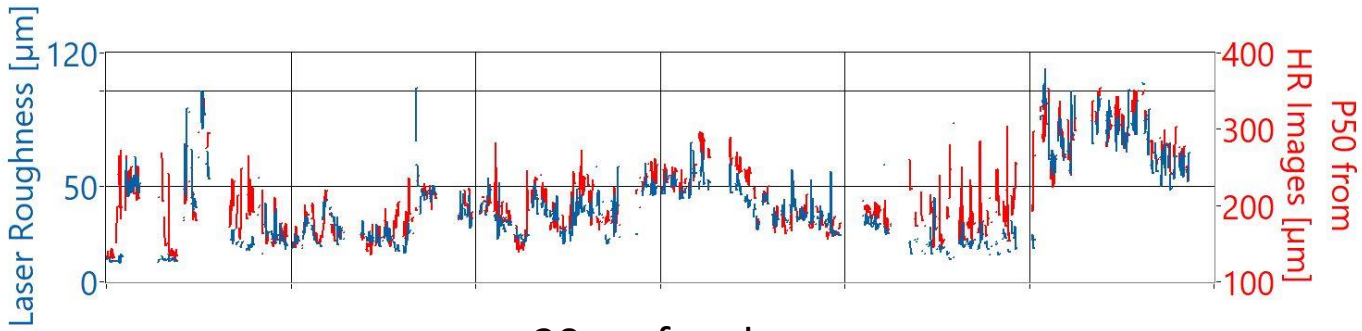
Norm. Pixels BW value



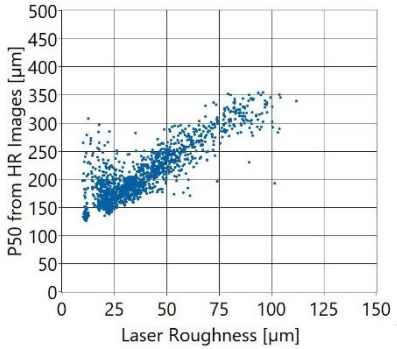


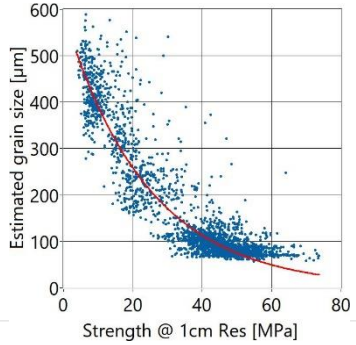




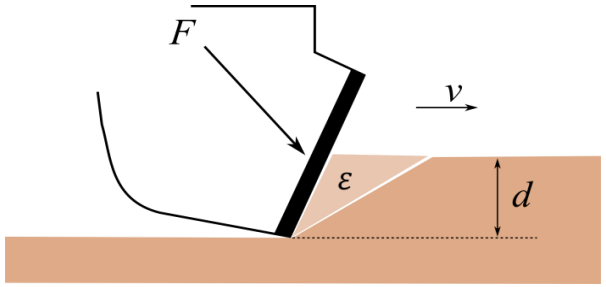


30m of rock





ROCK CUTTING

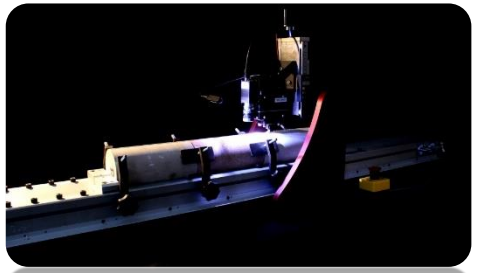


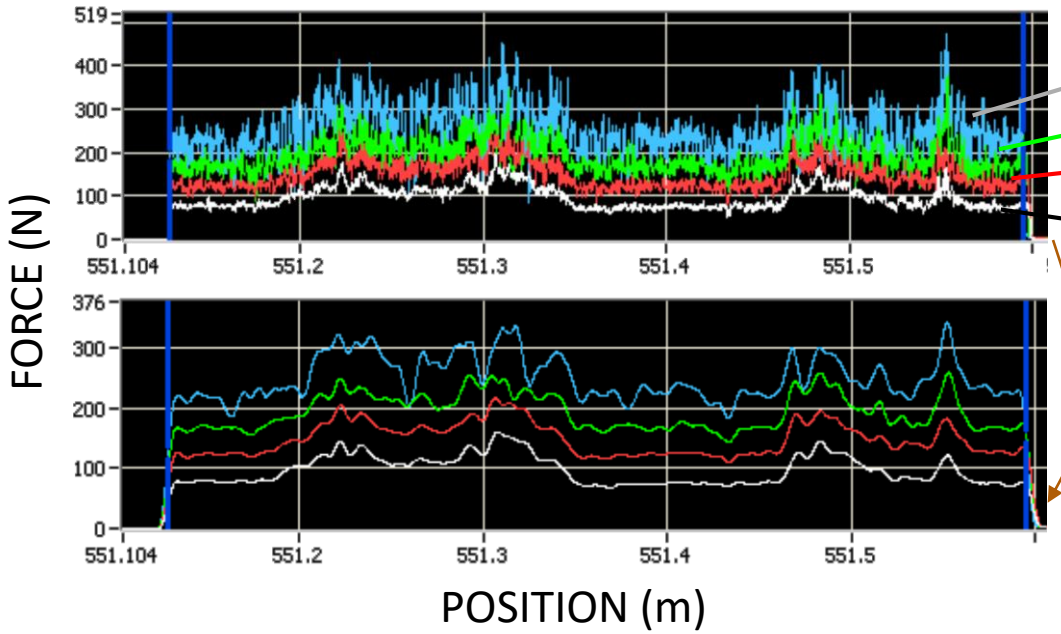
work performed by cutter

$$W = \varepsilon \times V$$

Strength

volume of rock cut





d = 0.5 mm

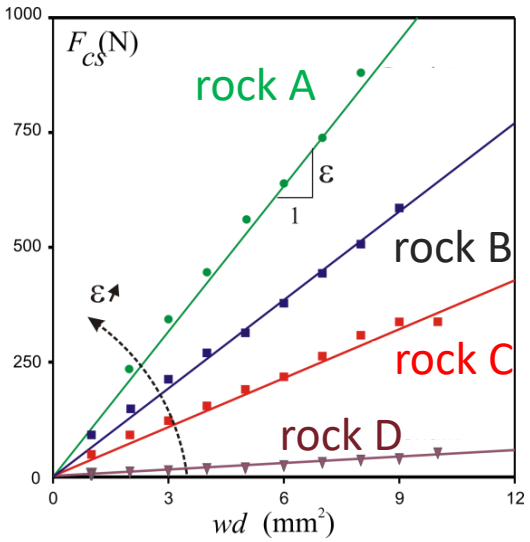
d = 0.4 mm

d = 0.3 mm

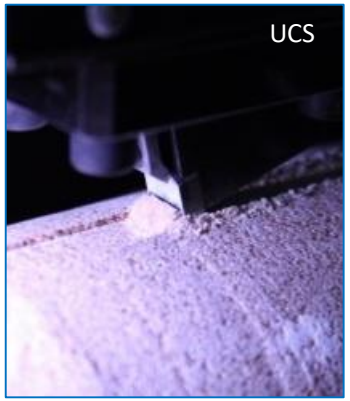
d = 0.2 mm

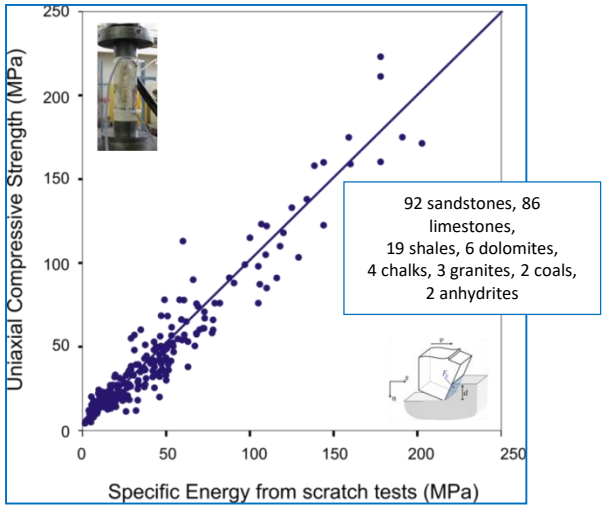
averaging

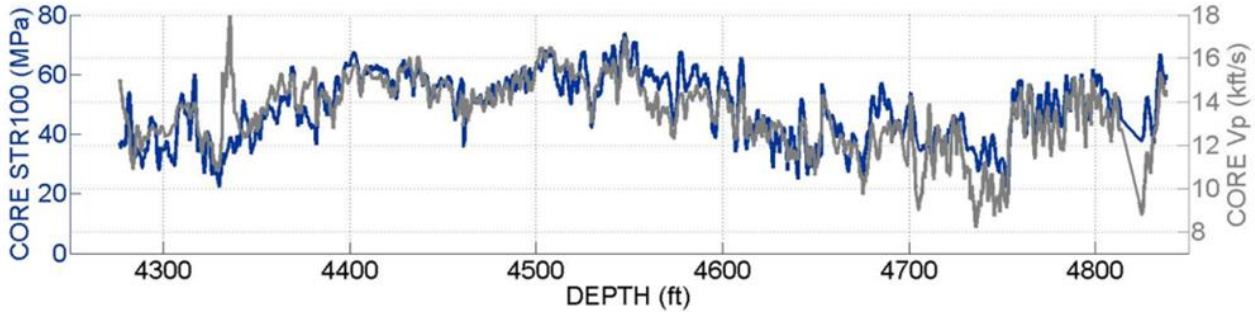
- CONSISTENCY
- REPEATABILITY

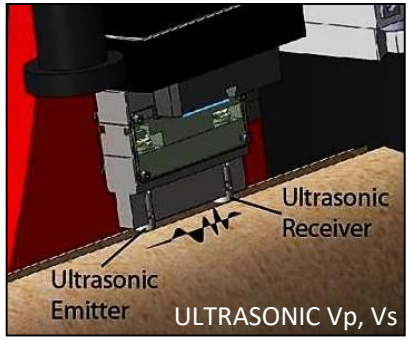


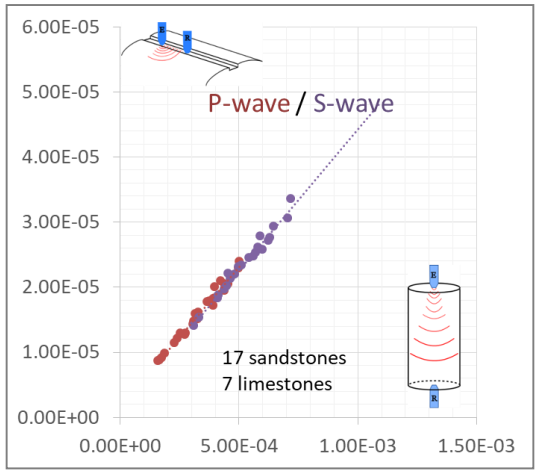
ROCK CUTTING & Vp, Vs

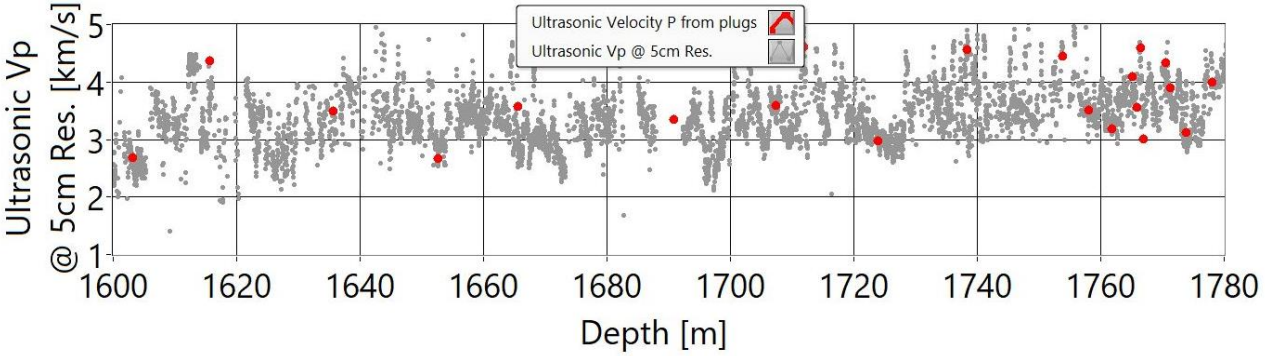








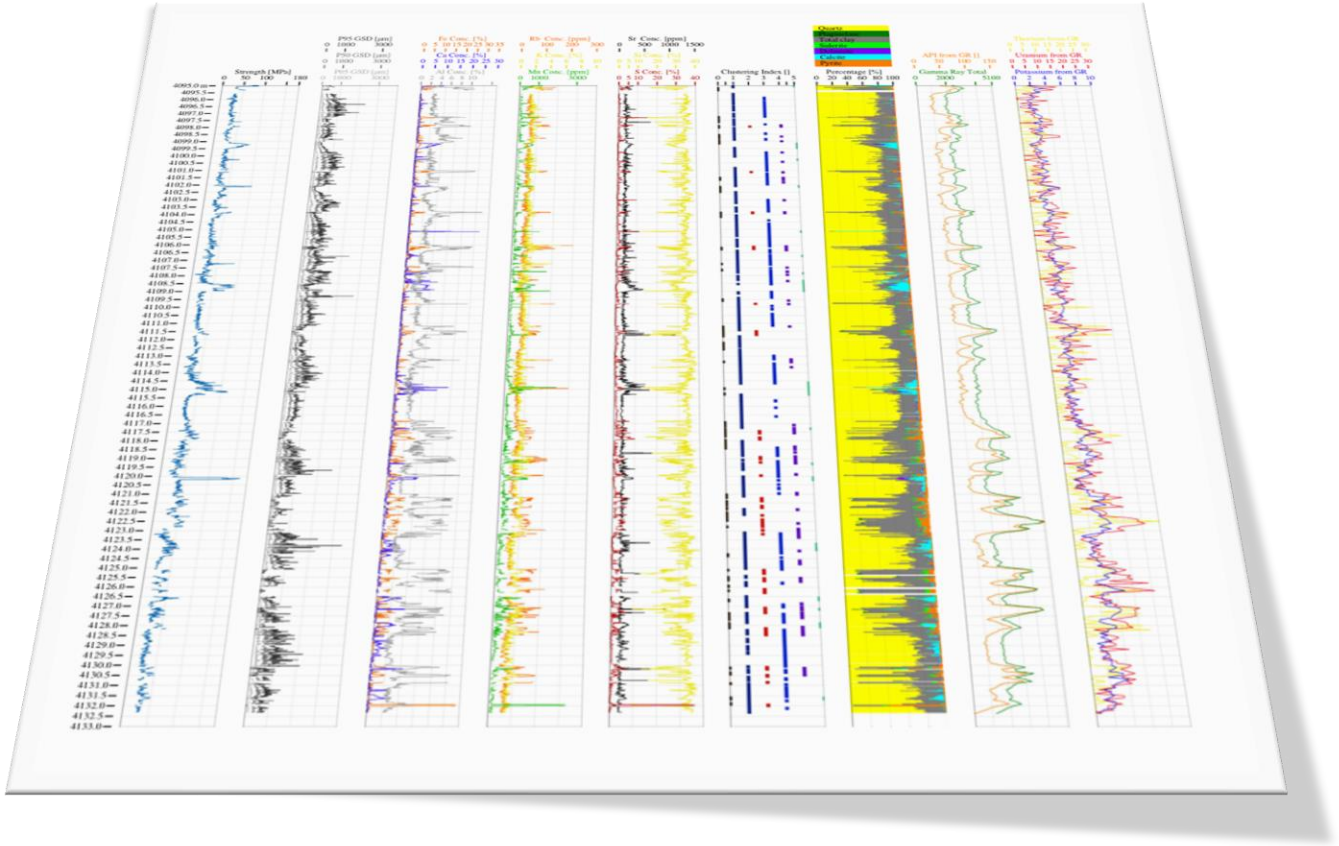




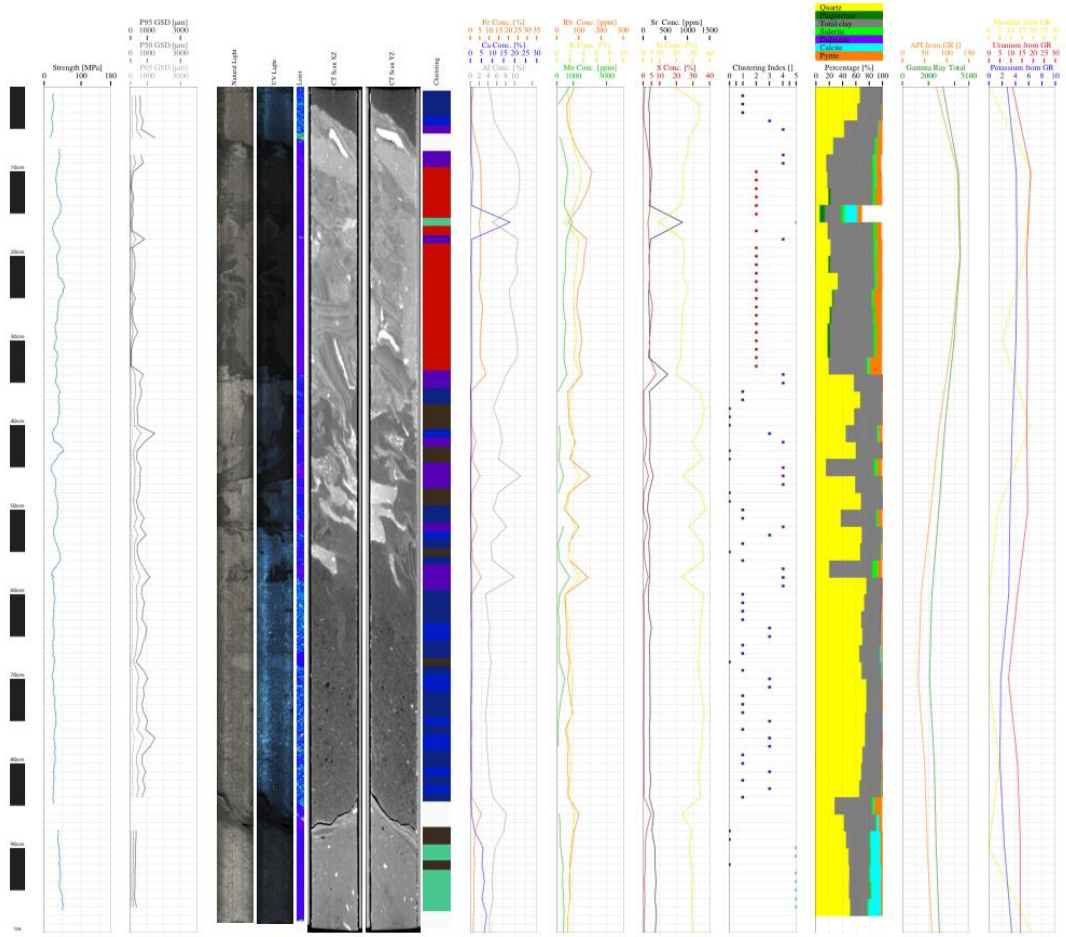
CORE DNA REPORT

- All data at one place
- Hyperlinks to navigate in or to the core photos
- General core overview or centimetric description

Core Overview



Detailed Description per meter section



MORE KNOWLEDGE SOONER

- **MULTI-SENSOR BENCH: ALL DEPTH SYNCRHONIZED** HIGH RESOLUTION SUITES OF MEASUREMENTS (1CM OF ROCK SAMPLE)
- RAPID AND NON DESTRUCTIVE TESTS & ANALYSIS / EARLY IN CORE ANALYSIS WORKFLOW;

Generation of big data

Facies characterization (properties statistics per facies)

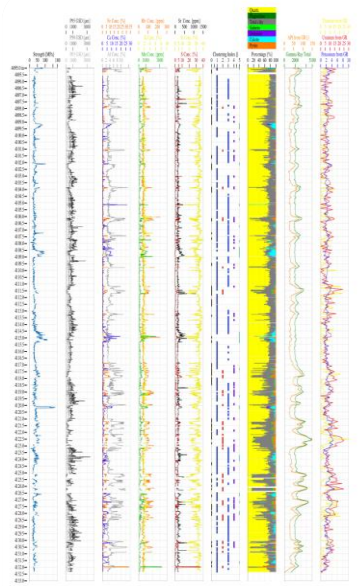
Prediction of reservoir quality indexes

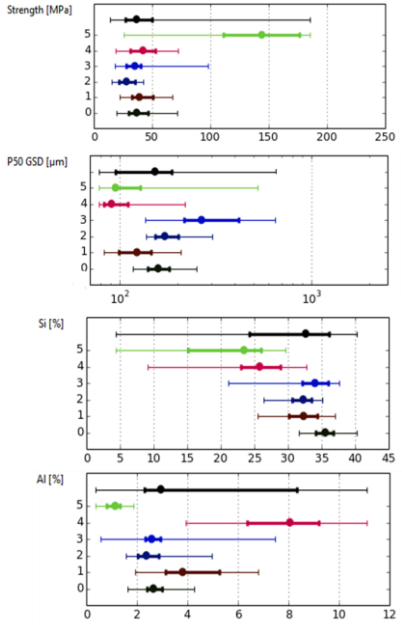
Adaptive Sample Sites selection

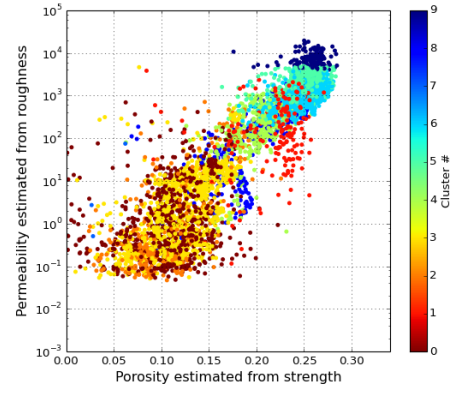
Qcing of Test results

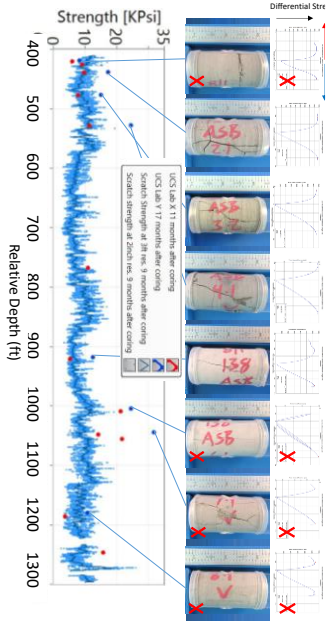
Upscaling discrete test results

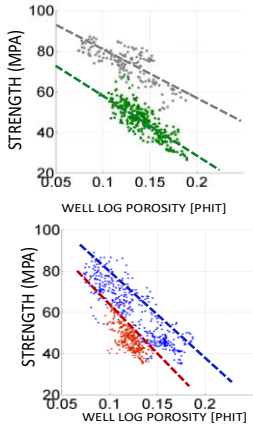
Establish robust and reliable proxies with wireline logs



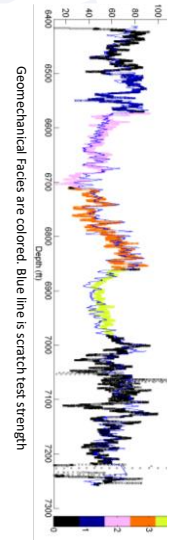








$$\mathrm{UCS(MPa)} = c\phi + d\frac{V_p}{V_s} + \mathrm{e}$$



CASE STUDIES

UPSCALING

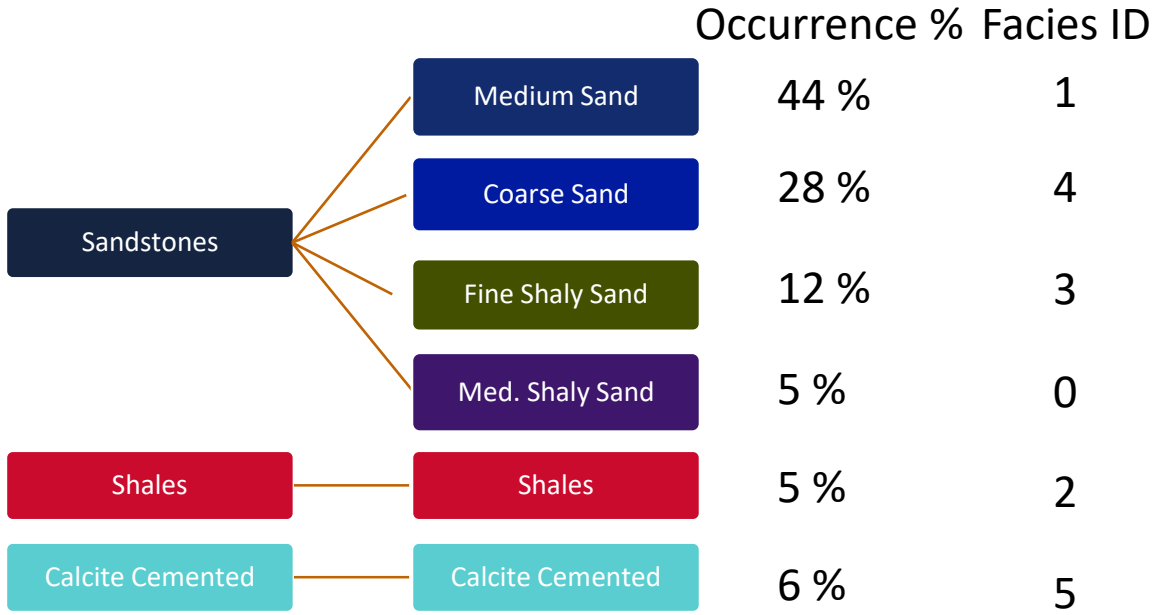
FACIES IDENTIFICATIONS

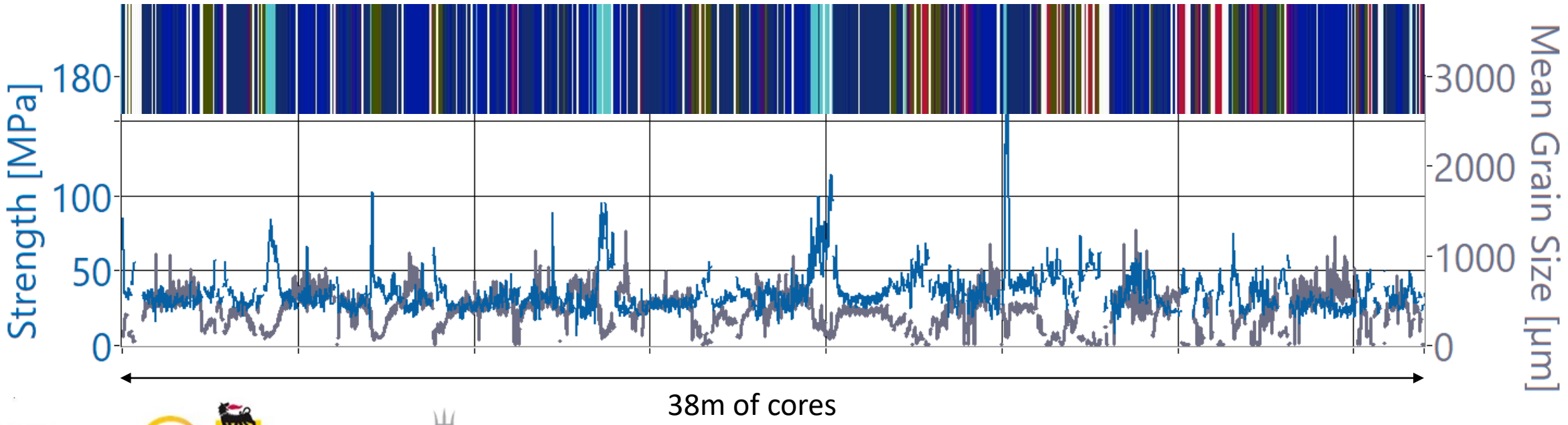
RESERVOIR QUALITY CHARACTERIZATION

REPEATABILITY / RELIABILITY

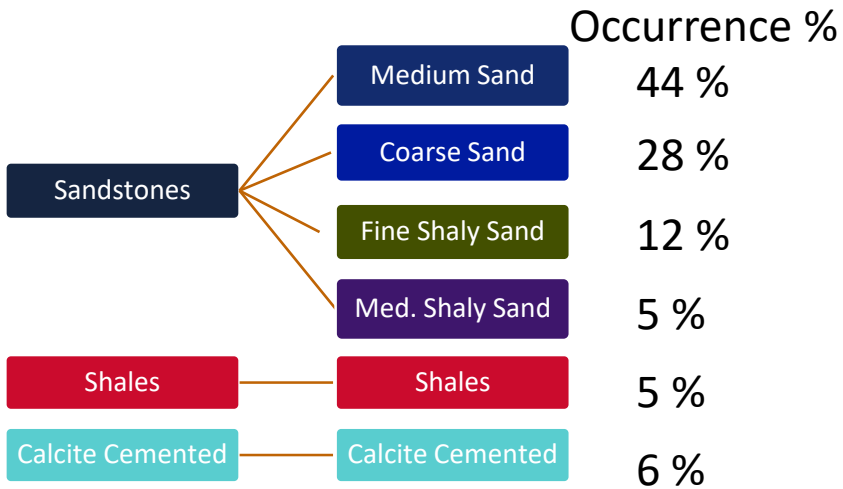
FACIES ID: UNSUPERVISED ML

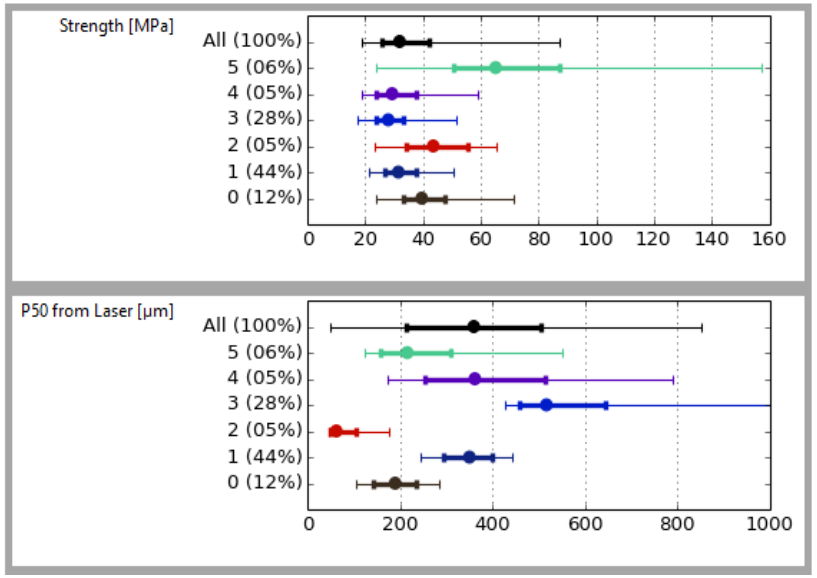
- Once we apply our clustering algorithm on the full set of data:
  - Strength
  - Mean Grain Size
  - Brightness, Color Indexes
  - pXRF

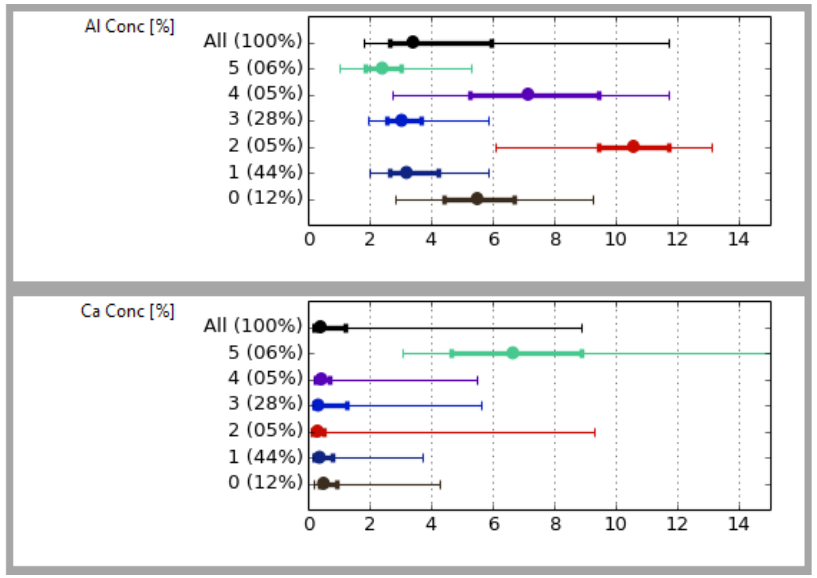


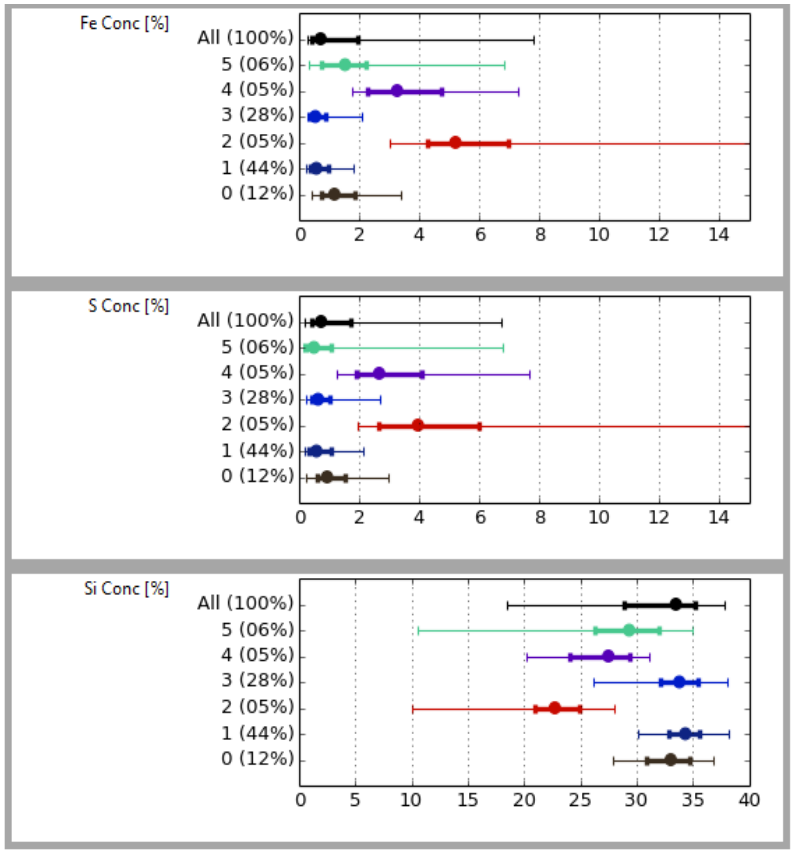


Facies statistics

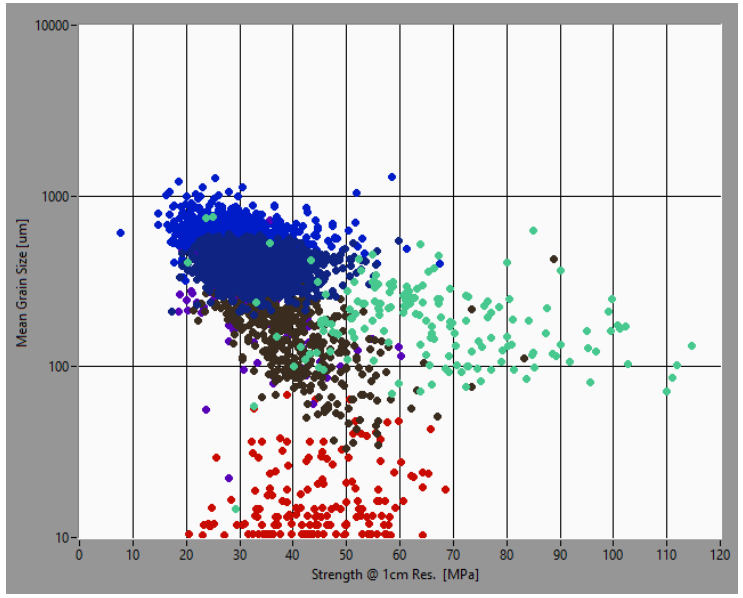


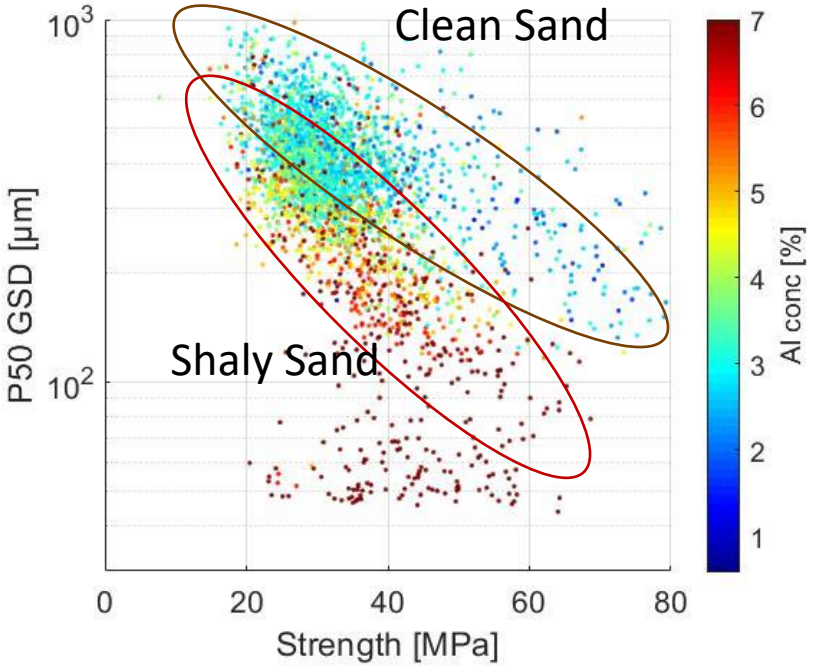






Ease and support the core understanding…

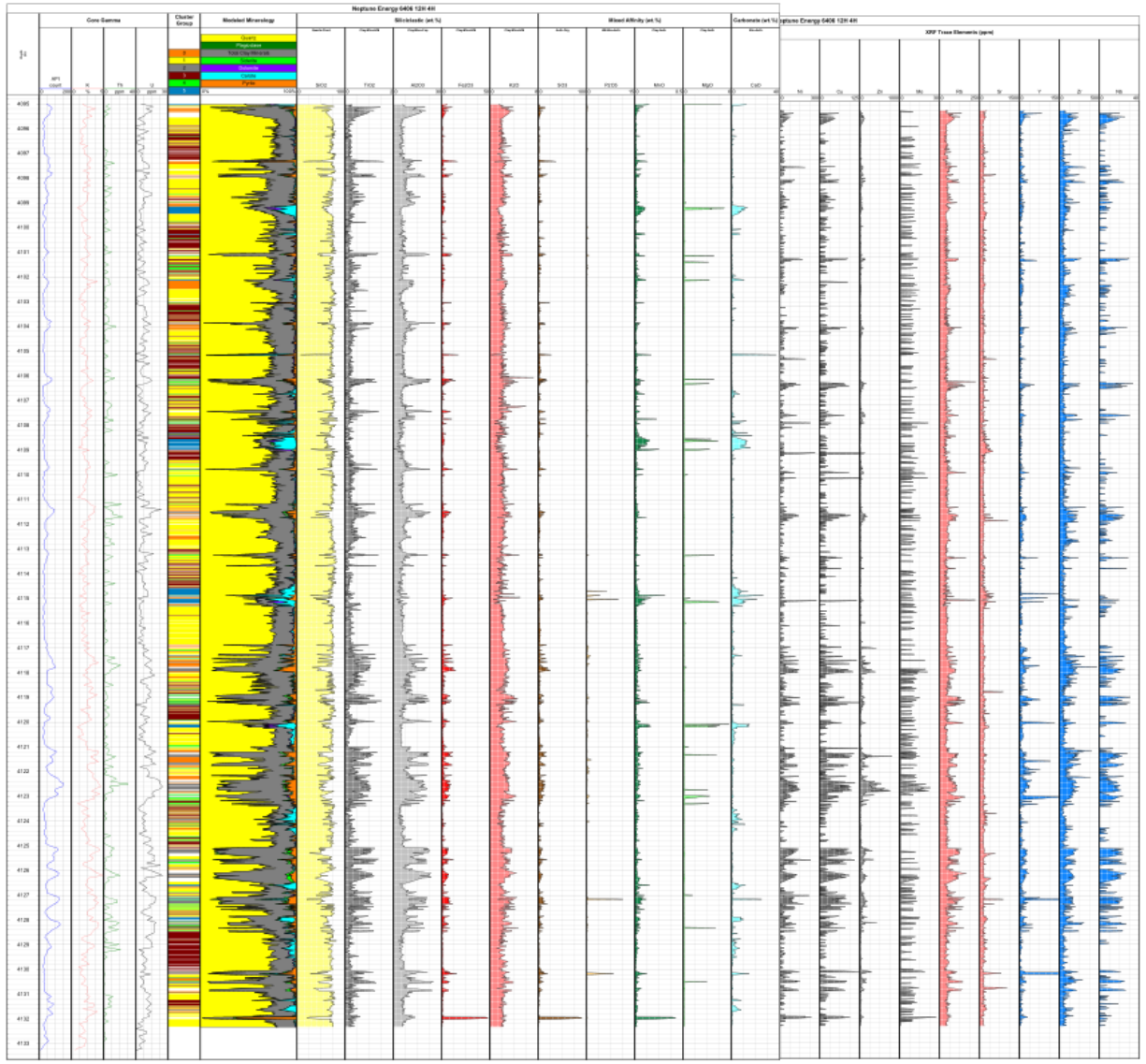




Al < 4%
Facies: 1, 3 & 5

Al > 4%
Facies: 0, 1, 2, 4 & 6

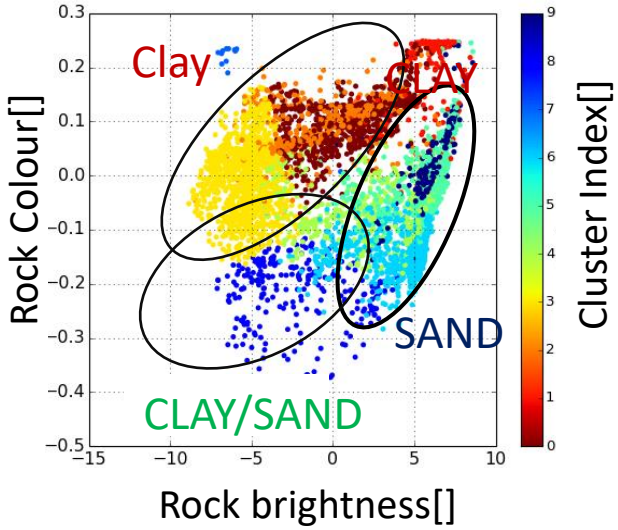
From Geochemistry to mineralogy…

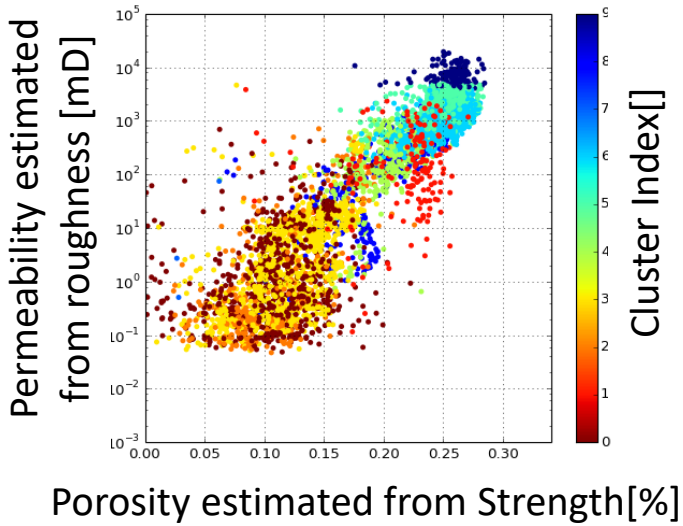


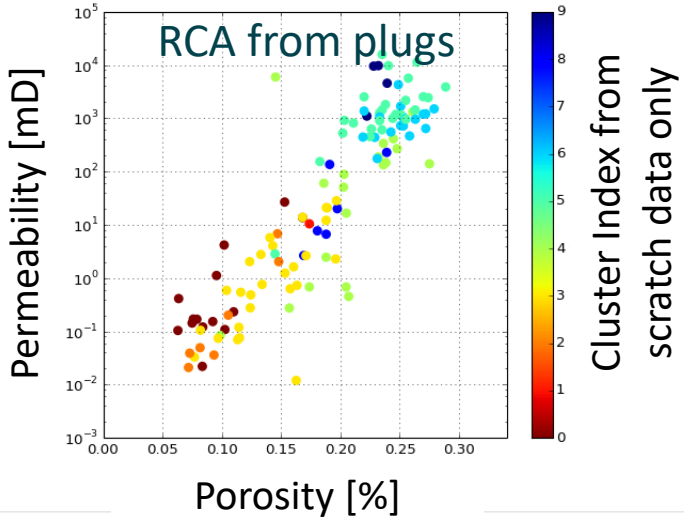
- Derive quantitative mineralogy from pXRF data;
- Very rapid analysis (one day or so);
- Could be integrated in the pre-sedimental description and facies identification;
- Estimates can be refined and callibrated with several XRD test specifically choosen.

RESERVOIR QUALITY MAPS

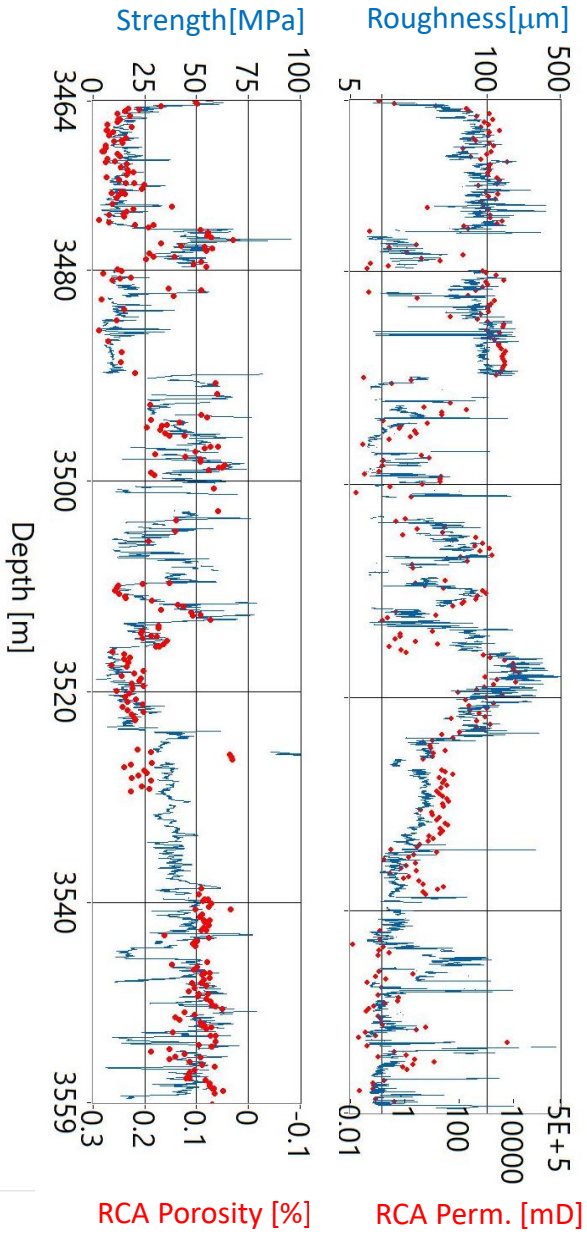
WOMBAT BENCH DATA ONLY



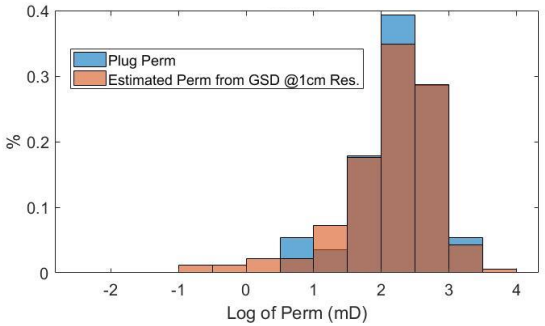


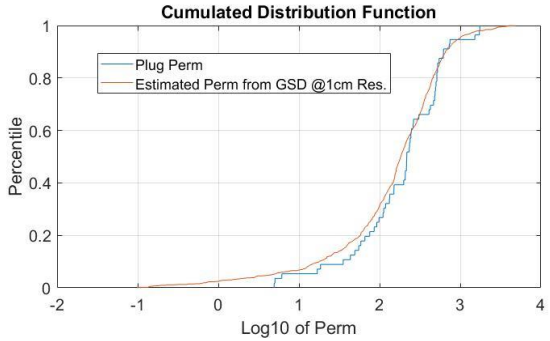


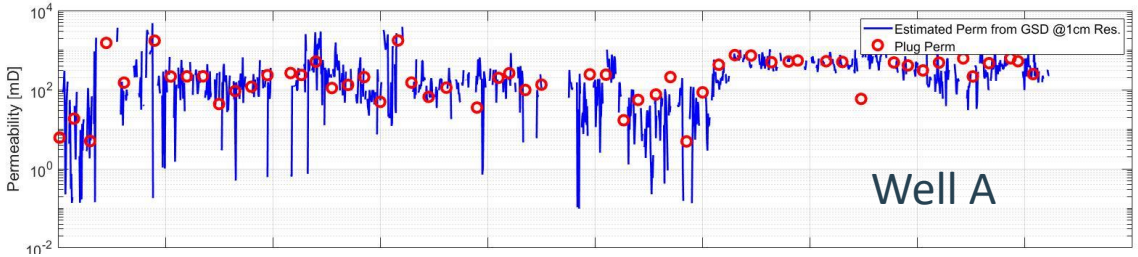
SCRATCH TEST RESERVOIR QUALITY ASSESSMENT VALIDATED BY RCA RESULTS RECIEVED MONTHS LATER



NET RESERVOIR ESTIMATION AT BARREL OPENING

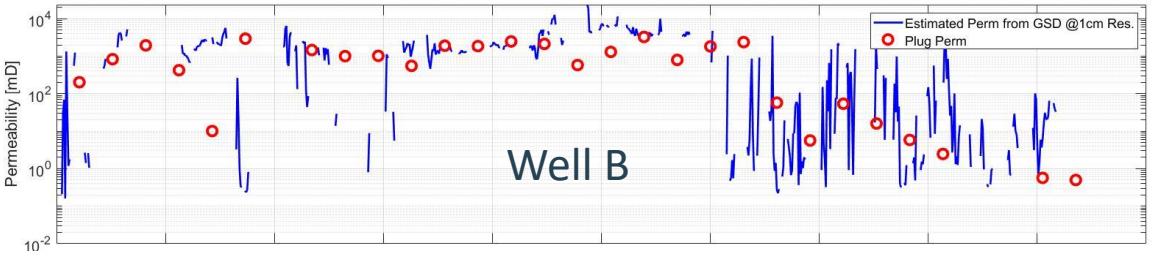


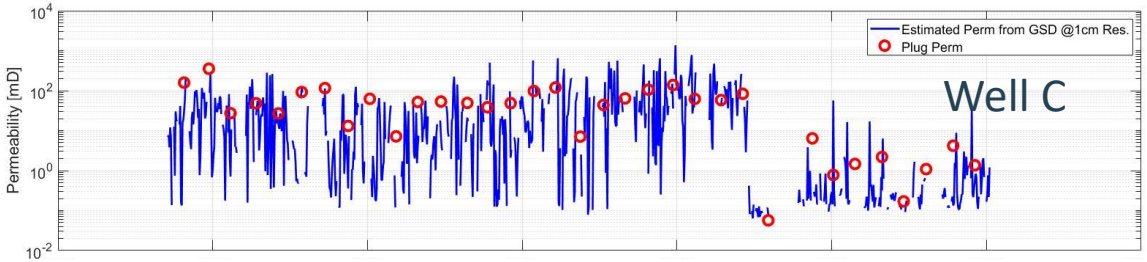




Depth Interval: 20m

Same equations to derive perm from grain size for all wells.

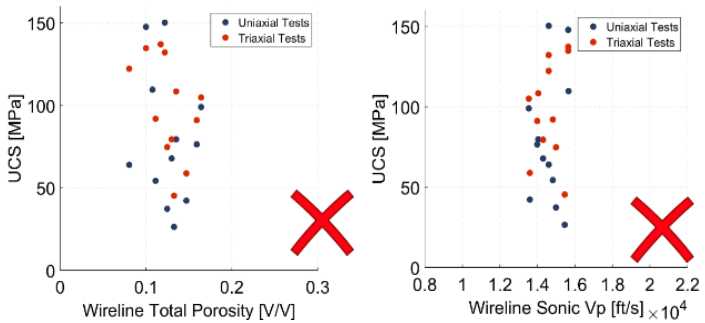




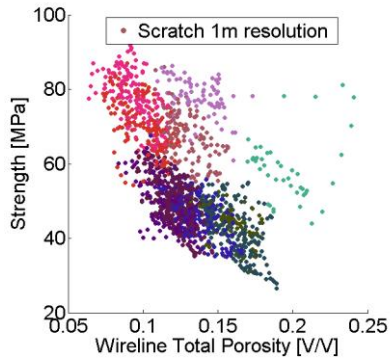
In collaboration with Mr I. Marzuki (PETRONAS)

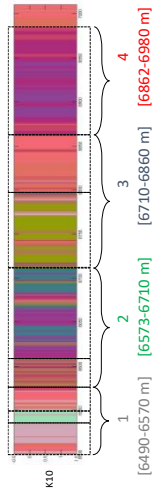
FACIES & UPSCALING

PLUGS DATA
NO TRENDS

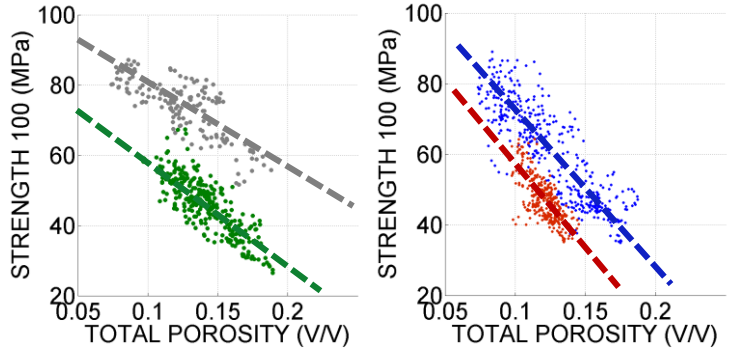


MULTI SENSORS
WOMBAT BENCH DATA

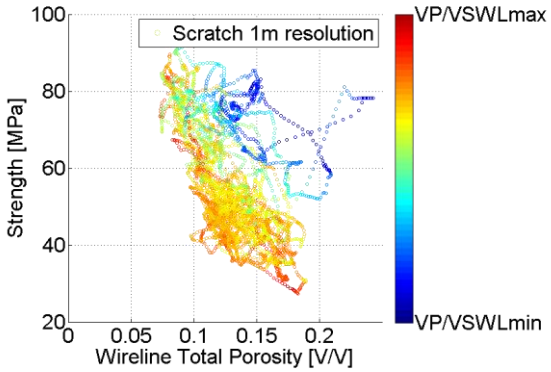




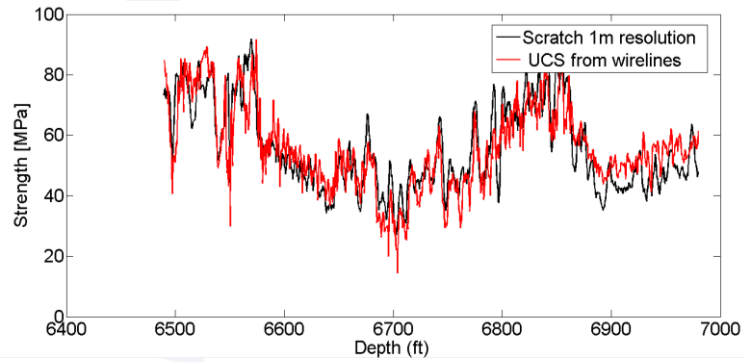
EXISTENCE OF GEOMECHANICAL FACIES WITH SCRATCH TEST DATA



BIG DATA – ROBUST PROXY FROM WIRELINE DATA

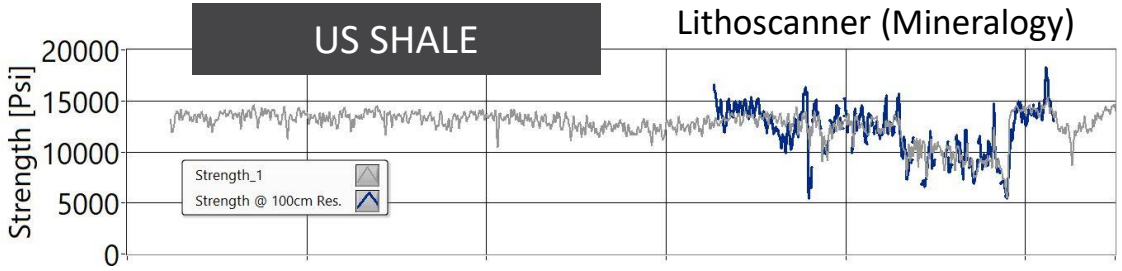


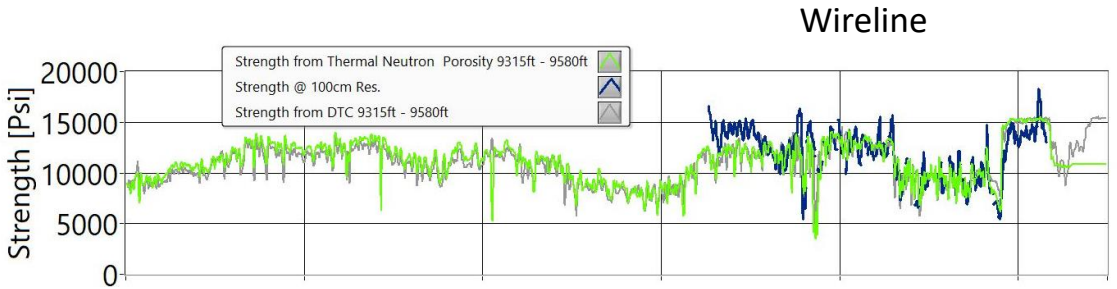
$$\mathrm{UCS(MPa)} = c\phi + d\frac{V_p}{V_s} + \mathrm{e}$$

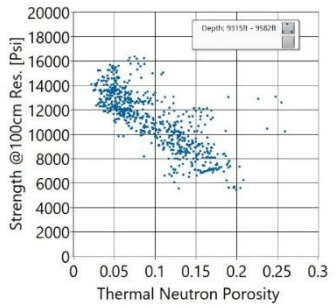


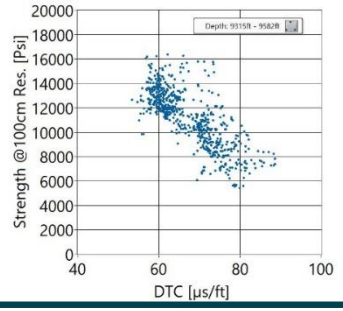
STRENGTH PROXY

US SHALE

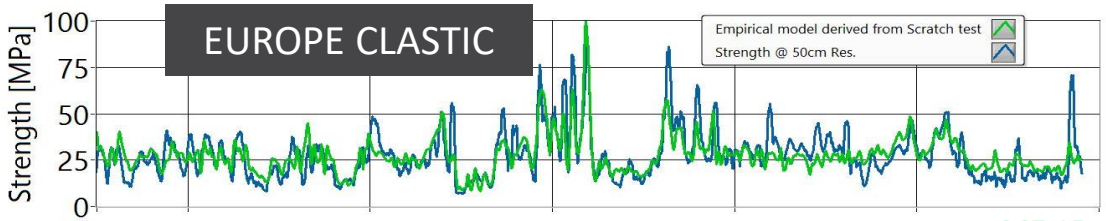




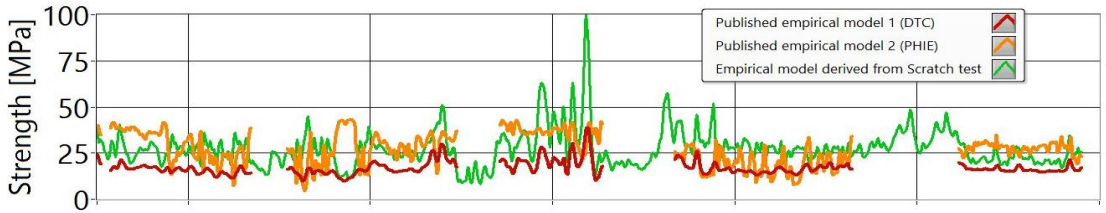




EUROPE CLASTIC



$$UCS = 831.3\ \mathrm{TNPH}^2 - 660\ \ \mathrm{TNPH} + \ 33\ \ + \frac{267.15}{\mathrm{DENS}}$$

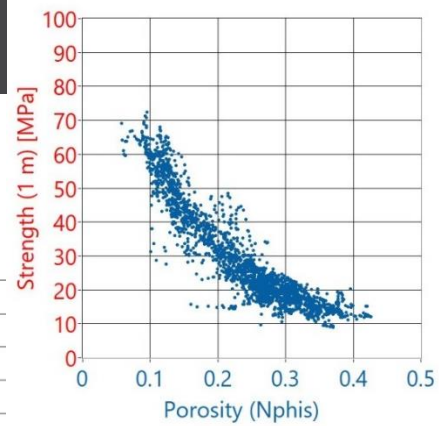


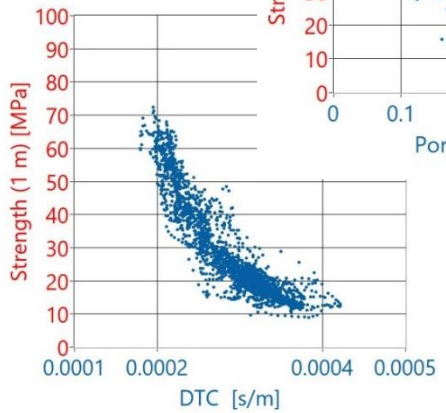
Calibrated with STR from one well

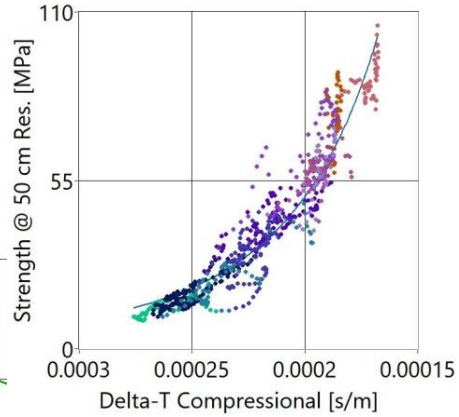
ROBUST MULTI-VARIATES PROXY

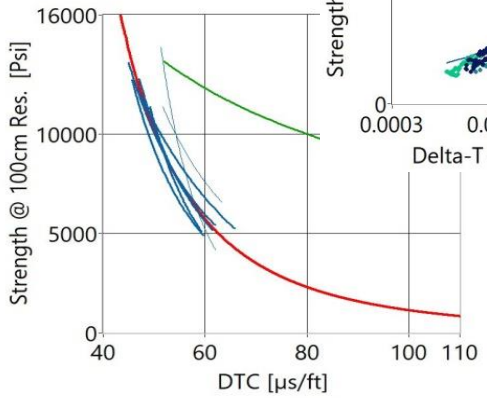
Calibrated with UCS from 3 wells

MIDDLE EAST CARBONATES









THANK YOU…

QUESTIONS?

VALUE PROPOSITION

UNIQUE MULTI-SENSORS

TRANSPORTABLE BENCH

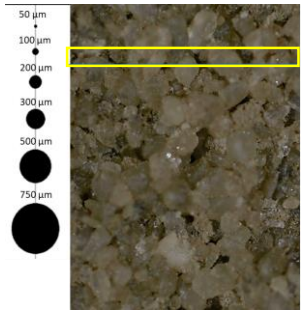
- 15 YEARS OF EXPERIENCE / 15 MILES OF CORE TESTED
- ALL MEASUREMENTS TAKEN SUCCESSIVELY WITH ONE UNIQUE DEPTH REFERENCE
- RAPID: 60 ft/day, data delivered within few days after completion
- COSTS EFFICIENT: ~100 USD /ft
- ANY SAMPLE SHAPE (Full core , slabbed, museum slice)
- SMALL FOOTPRINT: no mechanical damage, repeatable test
- FRESH CORE TESTED RIGHT UPON BARREL OPENING
- HIGH RESOLUTION MEASUREMENTS – CM SCALE

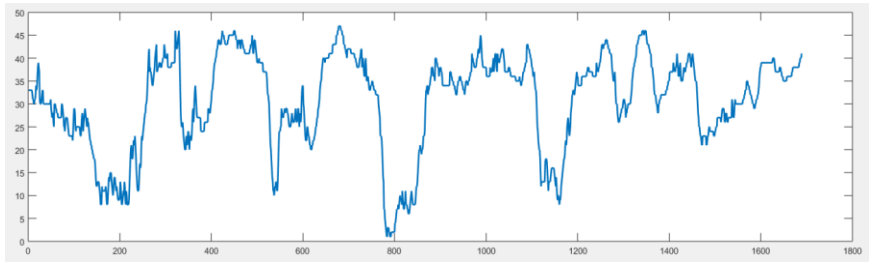
WOMBAT BENCH

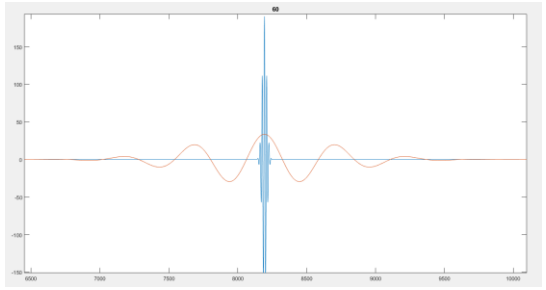
Your cores become the source of **QUALITY BIG DATA!**

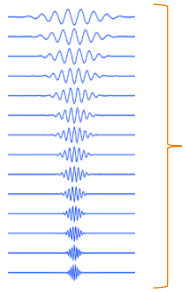
GSD – UHR images

Wavelet analysis can be compared to Fourier transform but wavelet is localized in both time and frequency while Fourier transform is just localized in frequency



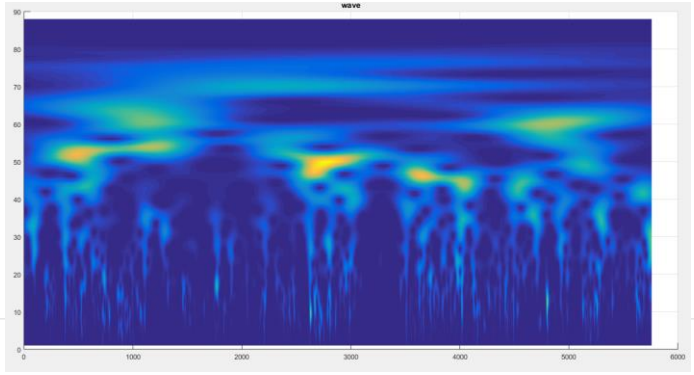






s scales

Scales



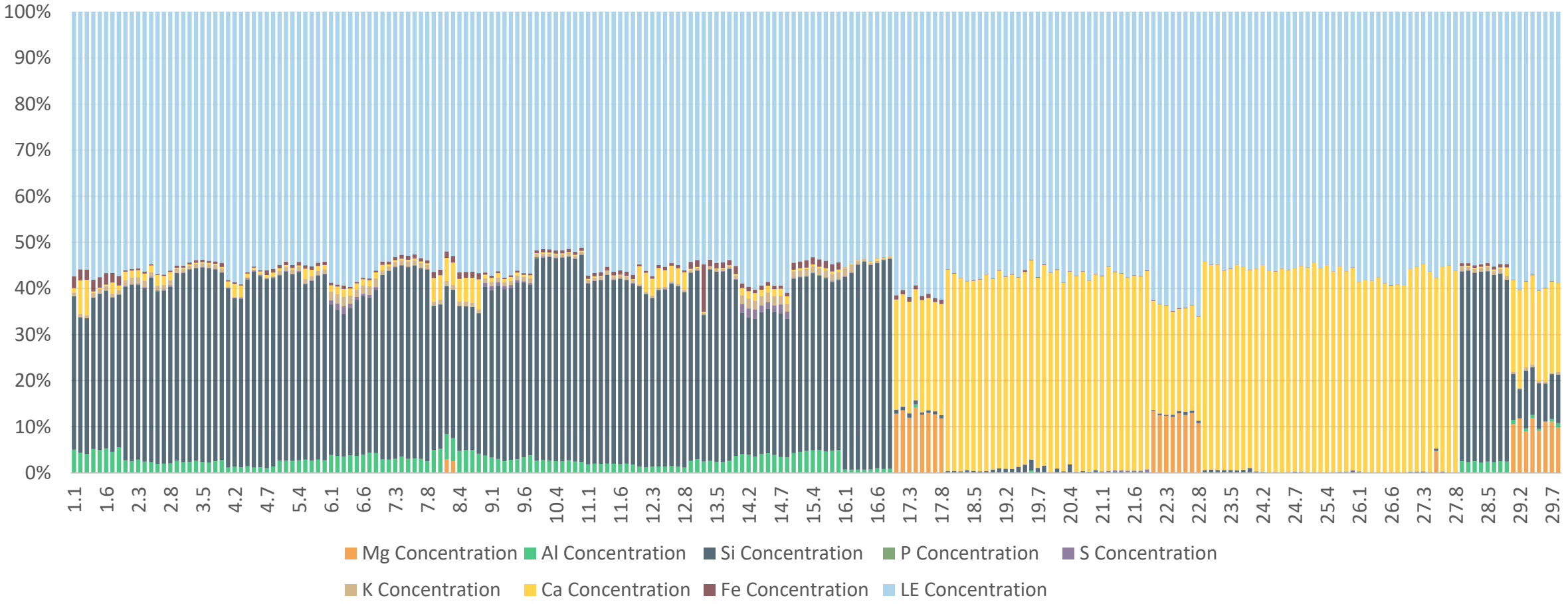
j

Results of steps 3 for a selected *j*

Process:

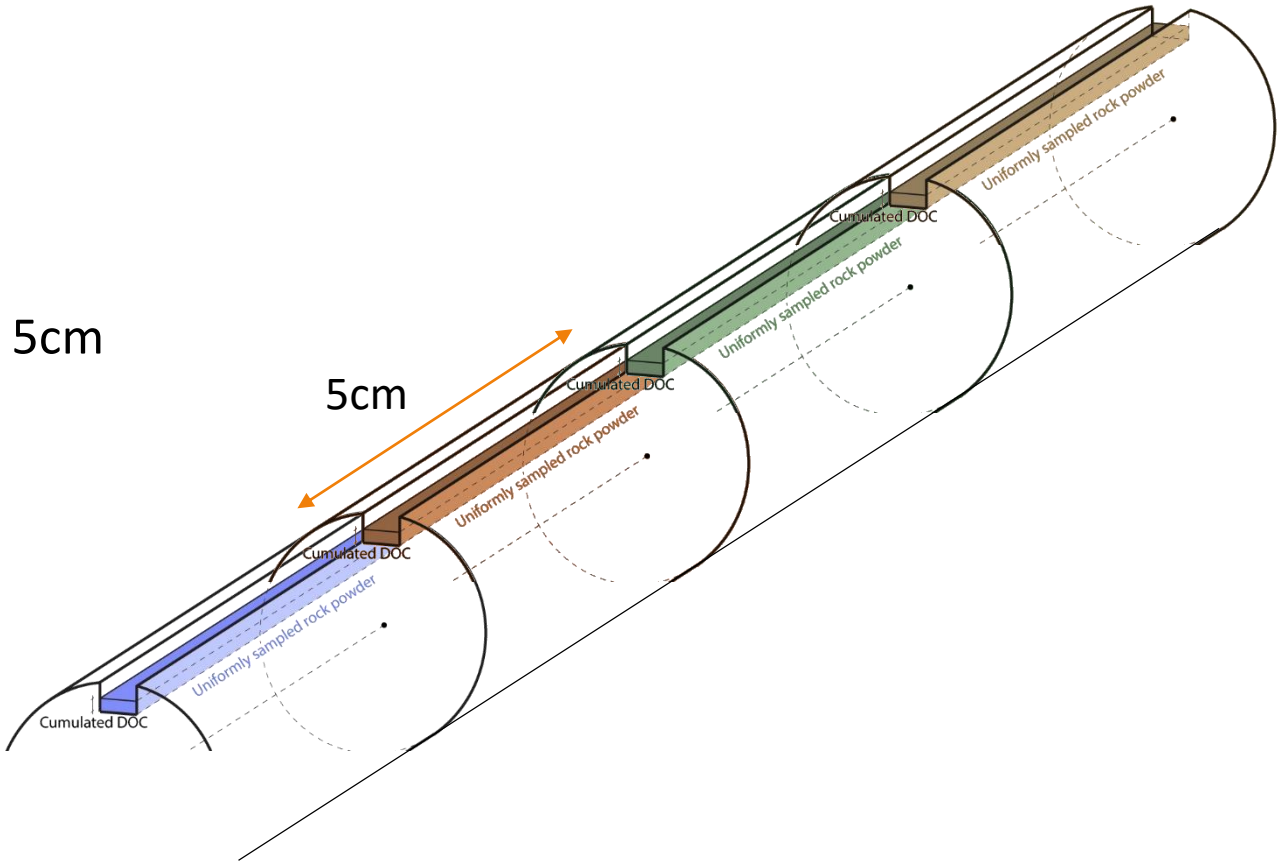
1. Extract lines of pixels of RGB picture and convert in gray scale ($Intensity_j(i)$ vector, $i=1:n$ pixels, j *lines* in each picture)
2. Calculate the convolution product of $W_j(i,s) = Intensity_j(i) * Wavelet(s)/\sqrt{s}$, where s is the scale the wavelet
3. Calculate $|W_j(i,s)|^2$ for each j,i,s
4. Average $\overline{W_j}^2(s) = \frac{1}{N}\sum_i |W_j(i,s)|^2$
5. Average $\bar{W}^2(s) = \frac{1}{M}\sum_j \overline{W_j}^2(s)$
6. Normalize $P(s) = \frac{\bar{W}^2(s)}{\sum_s \bar{W}^2(s)}$
7. Transform scale into equivalent grain size diameter P(s) ⟶ P(d)
8. Apply Kahn Fullman for volume equivalent (sieving)

Tests on 29 outcrop samples

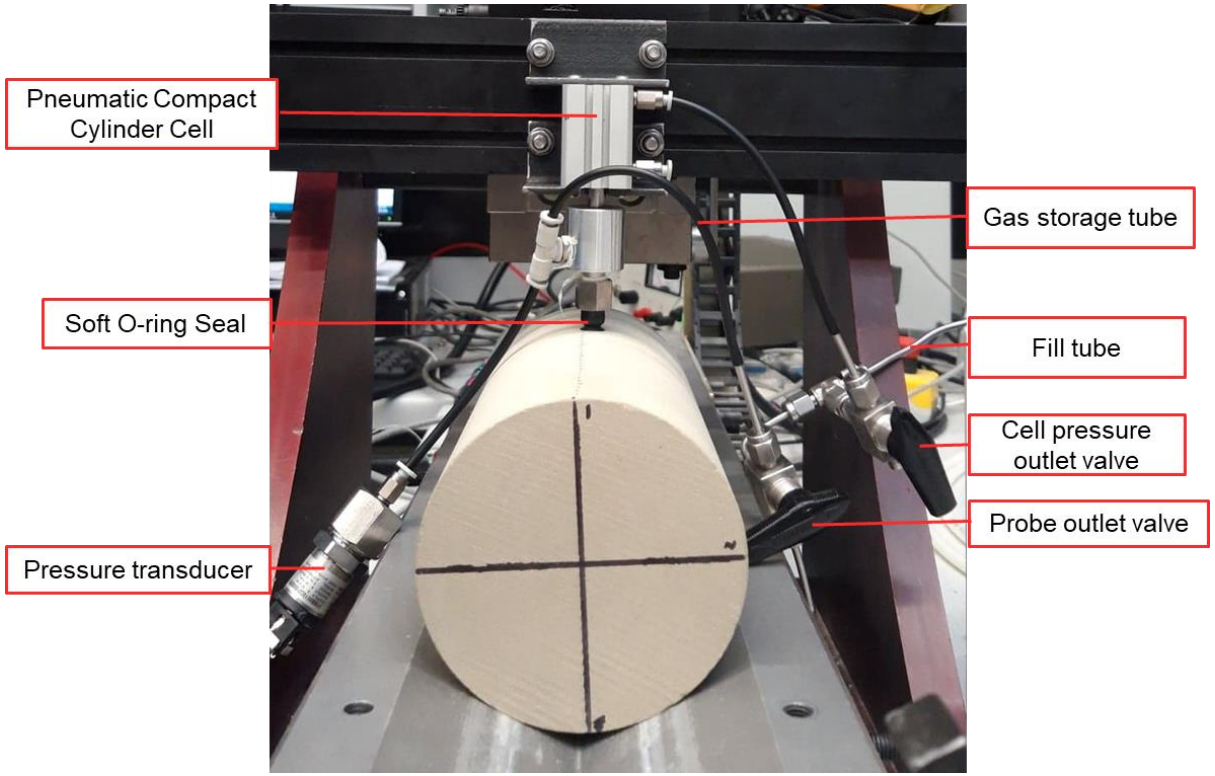


Continuous powder collection (upcoming development)

- Truly representative powder samples;
- Evenly sampled along the Surgicut
- Smallest intervals under considerations: 5cm



Probe permeability (unsteady state) (Upcoming development)



Particular development for Total SA