Webinars

Welcome!

The program will begin soon.
You will not hear audio until we begin.

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Webinars

Multi-Sensor Core Logging – The Future of Core Analysis

Craig Lindsay
Craig.Lindsay@core-specialist-services.com
Core Specialist Services
Society of Core Analysts Industrial Relations Liaison

SPE Reservoir Technical Discipline‘s Advisory Committee - Reservoir Technology of the 21ST Century, sub-committee Core Analysis

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What do Core Analysts study?

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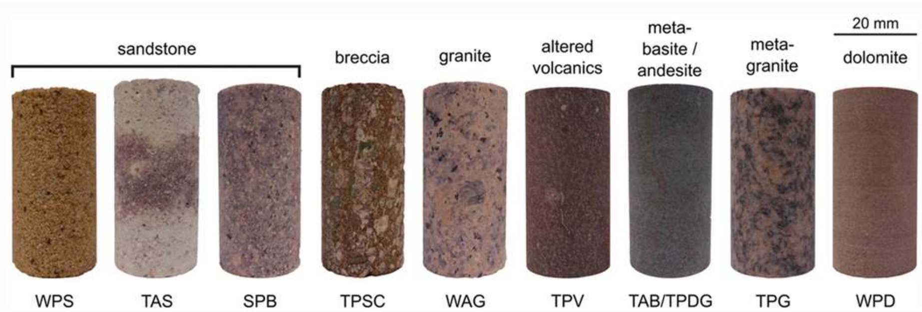
The properties of geological materials!



Photos of the rock samples prepared for physical property characterisation. *WPS* sandstone from Raon l'Etape, *TAS* sandstone from Waldhambach, *SPB* sandstone from Saint Pierre Bois, *TPSC* breccia from Albersweiler, *WAG* granite from Saint Pierre Bois, *TPV* hydrothermally altered volcanic rock from Albersweiler, *TAB* hydrothermally altered andesite from Waldhambach, *TPDG* metabasite from Albersweiler, *TPG* metagranite from Albersweiler, *WPD* dolomite from Raon l'Etape

Characterizing the physical properties of rocks from the Paleozoic to Permo-Triassic transition in the Upper Rhine Graben

Alexandra R. L. Kushnir, Michael J. Heap, Patrick Baud, H. Albert Gilg, Thierry Reuschlé, Catherine Lerouge, Chrystel Dezayes & Philippe Duringer

Geothermal Energy 6, Article number: 16 (2018) | Cite this article

https://geothermal-energy-journal.springeropen.com/articles/10.1186/s40517-018-0103-6/figures/3

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This presentation….

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- Material is included from a wide range of sources
- Inevitably vendor specific equipment are show
- Vendor specific workflows are illustrated
- Custom ML / AI workflows are illustrated
- There is no intended bias by the author for any specific provider, workflow or analytical method
- Other providers of above may be equally capable and have alternate approaches – there is no malicious intent by their omission
- All sources are referenced / credited where possible
- The intention is to inform / enlighten

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THANK YOU TO ALL SOURCES

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Traditional and Current Instrumentation Routine Core Analysis (RCA, CCA)

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Mainly specific to conventional oil and gas reservoirs.

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Traditional and Current Instrumentation Special Core Analysis (SCAL)

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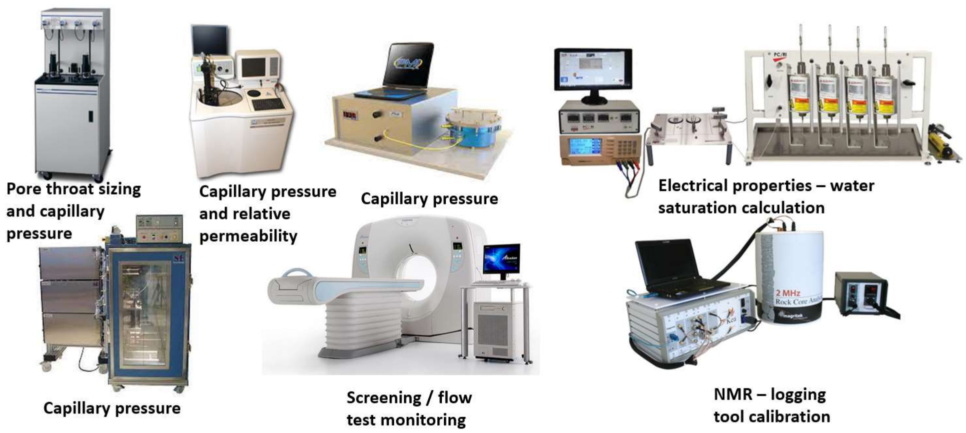

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Mainly specific to conventional oil and gas reservoirs.

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Analysis of Unconventional Core (shale, tight gas)

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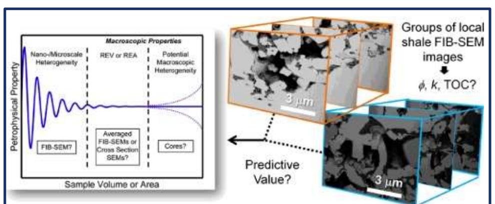
Generally much more problematic;

- Very low permeability and porosity = problematic
- Hydrocarbons not in pores (adsorbed)
- No standard instruments / no agreed standards = data difficult to compare
- Many "conventional" tests difficult or impossible
- Some "heritage" methods still used – retort, GRI (crushed core) = qualitative
- Rock mechanics important - for fracing
- Digital methods more practical (time, cost and feasibility)?
- Core / log integration very important



Assessing the utility of FIB-SEM images for shale digital rock physics

Shaina Kelly, Hesham El-Sobky, Carlos Torres-Verdín, Matthew T. Balhoff

Rock mechanics

Schlumberger

Permeability Measurements

In the GeoMechanics lab we run permeability tests over a wide range of permeability space, from loosely consolidated sands to tight gas shales. We have four distinct systems to measure permeability: a Darcy permeameter, derived through low-pressure triaxial testing, on mudstone samples during CRS testing, and steady state or pulse transient decay permeability on tight gas shales in a biaxial core holder.

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Understanding How Worlds Work

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Mudrock digital analysis = Complex & High Tech.

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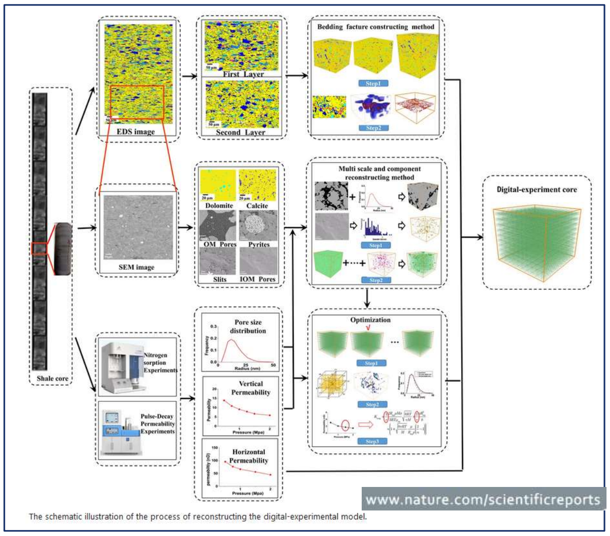

The schematic illustration of the process of reconstructing the digital-experimental model.

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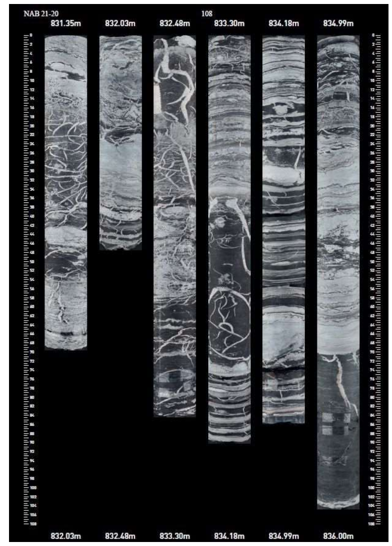
A core-scale reconstructing method for shale

Lili Ji[1], Mian Lin[1,2], Gaohui Cao[1,2] & Wenbin Jiang[1]



Arbeitsbericht NAB 21-20 Dossier II https://www.nagra.ch/de

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Sampling for standard Core Analysis Studies

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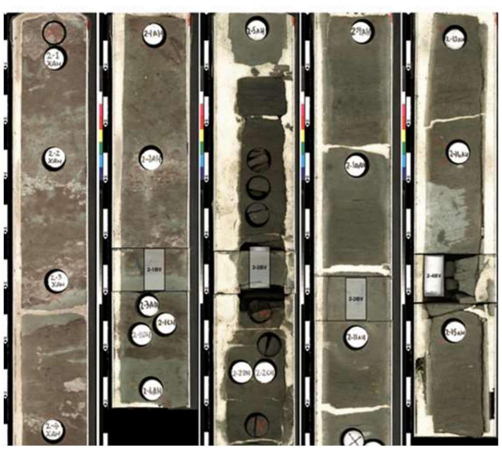

Industry standard practice for core sampling;

- **RCA every 25 cm or 1 ft.**
- **SCAL several per facies type (guided by RCA)**

Standard sampling methods barely scratch the surface in terms of truly representing the core properties & only provide snapshots of core properties

The same applies a wide core based studies such as geomechanics, petrography, geochemistry, formation damage and many more

ONLY standard "continuous" data are core gamma, probe permeability and core imaging.

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How representative is your digital core analysis sample?

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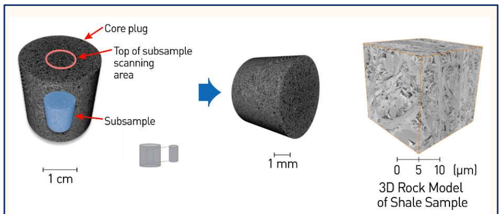

Scan type	ROCK SAMPLE SIZE	RESOLUTION RANGE	APPLICATION
3D whole core scan	10 cm to 1 m long 2.5 to 25 cm in diameter	100 μm to 0.5 mm	Density logging Core plug selection Heterogeneity analysis Fracture analysis Digital core database
3D standard core plug scan	2.5 or 3.8 cm (standard)	12 to 40 μm	Geological description Heterogeneity study
3D subplug CT scan	1 mm to 2.5 cm	0.5 to 12 μm	3D detailed scan Microscale pore structure analysis
3D CT nano scan	2 or 200 μm	1 to 200 nm	3D detailed scan Nanoscale pore structure analysis
3D FIB nano scan	2 or 200 μm	1 to 200 nm	3D ultrahigh-resolution scan Pore network analysis on extreme samples (shale, tight gas, etc.)
2D nano scan	2.5 cm across or subareas	1 to 250 nm	Large FOV, nm to cm High-resolution image mosaics and analysis
2D mineralogy scan	2.5 cm across or subareas	12 to 50 μm	Mineral identification and analysis

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iRock Technologies
http://www.irocktech.com.cn/en/laboratories/

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The SCALE problem?

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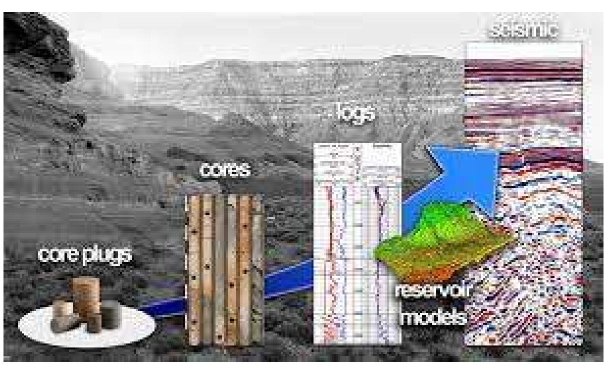

- The age old problem of scale
- Core plugs don't capture heterogeneity on a core scale
- Digital core analysis samples probably don't capture heterogeneity on a core plug scale
- We cannot cut and analyze plugs / sub-samples from the entire core – cost / practicality / time
- Selecting relevant / representative samples is critically important (VOI, cost, time)
- A lot of money is spent on high cost / critical value core tests but sampling methodology is critical
- Traditional sampling methods / criteria are not fit for purpose

PRESION SAMPLING FOR ADVANCED STUDIES NOW POSSIBLE

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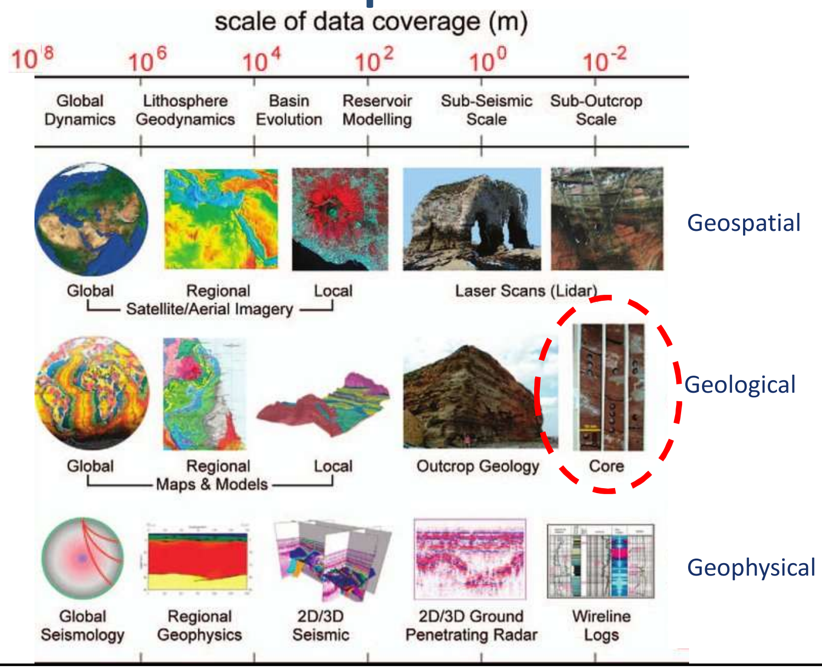
The SCALE problem?



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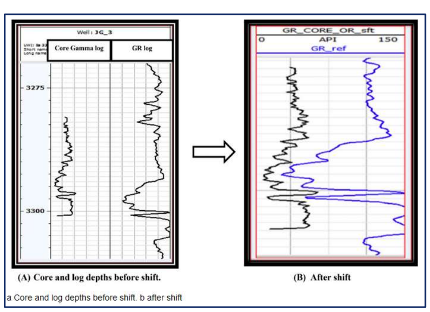
The Solution – continuous core data

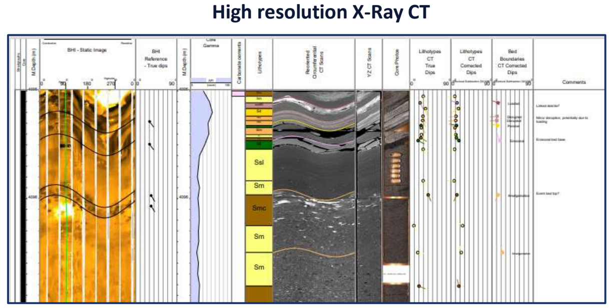
Continuous core data we have traditionally acquired

Core gamma ray

High resolution X-Ray CT



a Core and log depths before shift. b after shift



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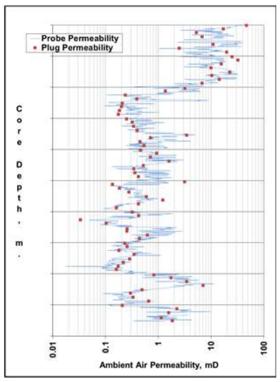
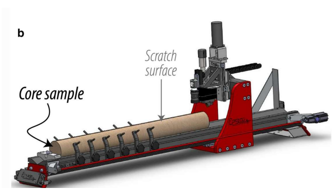
The Solution – continuous core data

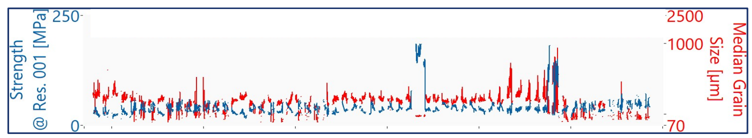
Continuous core data we have traditionally acquired contd.

Profile permeameter





Scratch test (UCS)



60m. of core

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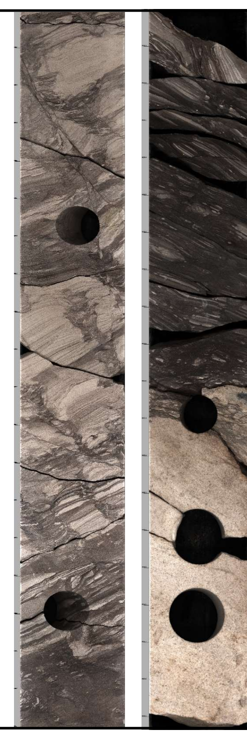
Core imaging then and now



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Permeability – How well is it Quantified from core plugs?

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Core plug measurements at 1 per ft. – may not fully characterise the level of permeability heterogeneity – especially in laminated formations

How do we know?

Hurst and Rosvoll – proposed method to determine minimum number of measurements (*No*) to determine Arithmetic Mean Permeability +-20%

Reducing the tolerances – unrealistic number of measurements

Calculate coefficient of variation,

Cv = Standard Deviation / Arithmetic Average

No = 100 Cv^2

HURST, A. and ROSVOLL, K.J. (1990) Permeability variations in sandstones and their relationship to sedimentary structures. 2nd International Reservoir Characterisation Technical Conference, Dallas

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Permeability versus Heterogeneity

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- Based upon Cv **Corbett and Jensen** proposed heterogeneity classes:
  - **0 - < 0.5 Homogeneous**
  - **0.5 - <1 Heterogeneous**
  - **>1 Very heterogeneous**

Three examples of applying these principles:

Rotliegend reservoir SNS

- 150 plugs acquired (1 per ft.)
- **Cv = 2.5, *No* = 625 Very heterogeneous**
- Plug alone data did not quantify permeability heterogeneity – probe permeability data @ 5 measurements per ft = **729** points.

(a). 30/24-27 Innes area

The Rotliegend reservoir in Block 30/24, UK Central North Sea: including the Argyll (renamed Ardmore) and Innes fields
Alan P. Heward, Paul Schofield and Jon G. Gluyas
Petroleum Geoscience, 9, 295-307, 1 October 2003, https://doi.org/10.1144/1354-079303-578

A Comparison of Small-Scale Permeability Measurements Methods for Reservoir Characterisation
Jan 1991
P W M Corbett · J L Jensen
Corbett, P. W. M., and J. L., Jensen, " A Comparison of Small-Scale Permeability Measurements Methods for Reservoir Characterisation," presented at the PSTI Advances in Reservoir Technology Conference, Edinburgh, February 21-22, 1991.

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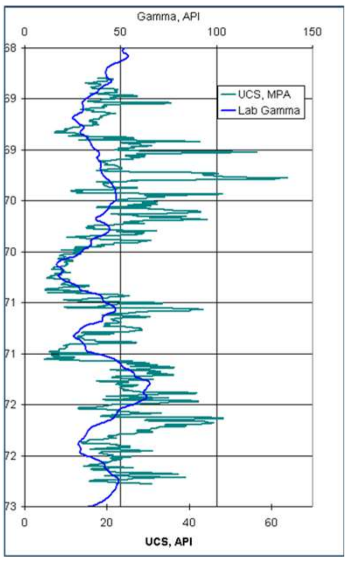
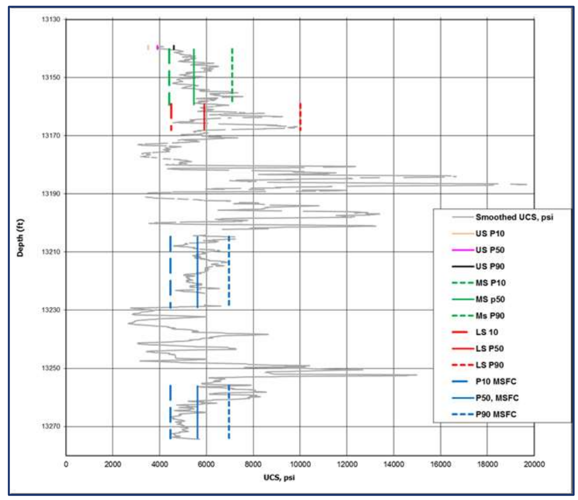
Why continuous core data – basic examples of data correlations



Rock strength & Gamma Ray?



UCS from scratch test to accurately define sampling points for rock mechanics study

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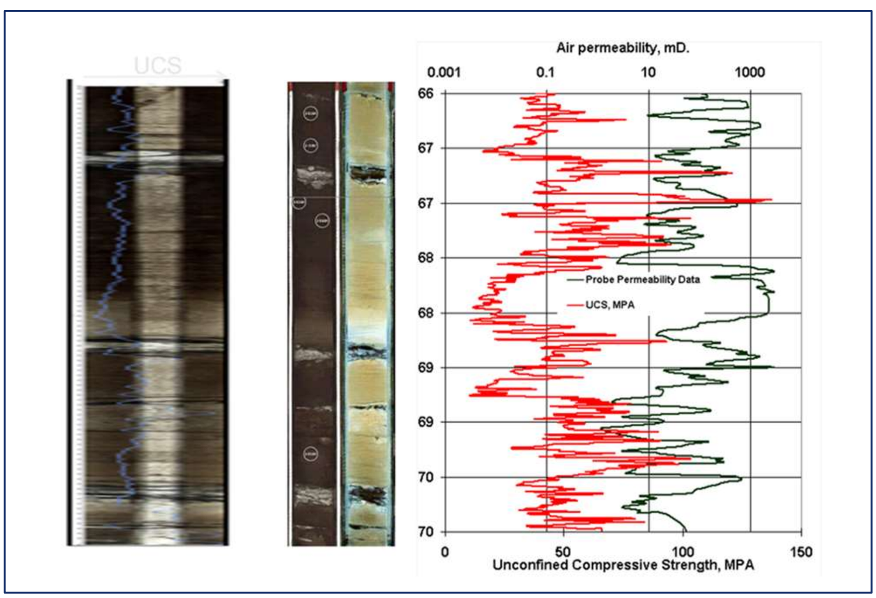
Why continuous core data – basic examples



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High Resolution Core Characterisation – Multi-Sensor Core Logging (MSCL)

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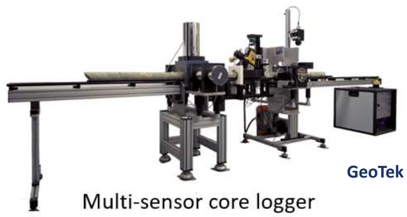
New workflows for new core & New life for old cores

GeoTek



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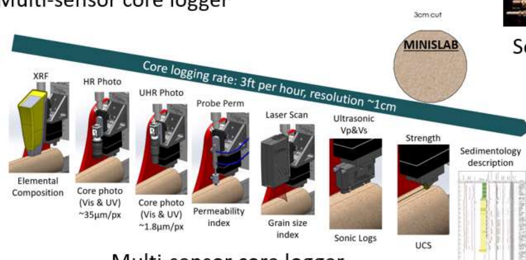
Multi-sensor core logger

Scratch Test

Epslog



Multi-sensor core logger

Epslog

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(Not so) Homogeneous Chalk?

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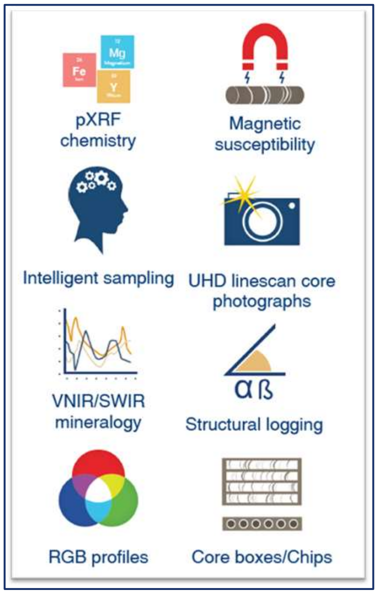
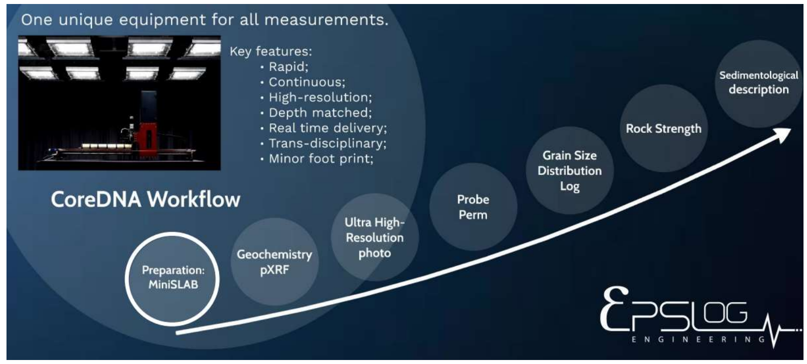
Example vendor workflows



GeoTek



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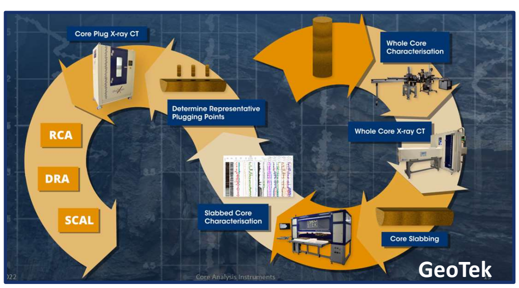
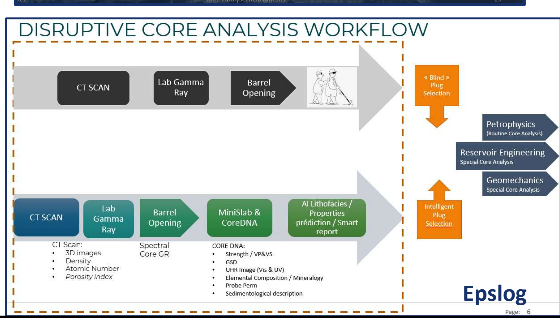
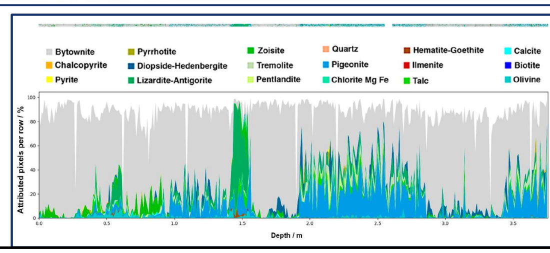
Example vendor workflows contd.





Epslog



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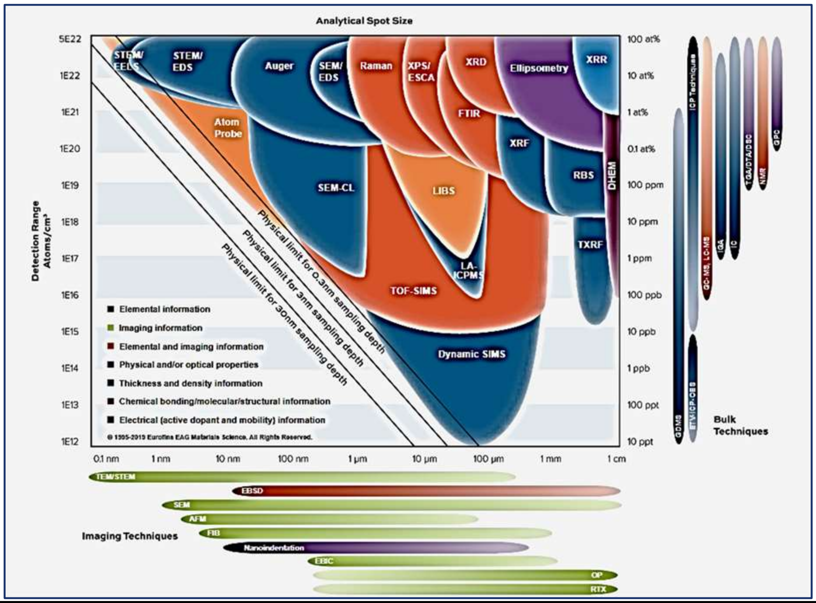
Mineral Characterisation Technologies



eurofins | EAG Laboratories

https://www.eag.com/techniques/

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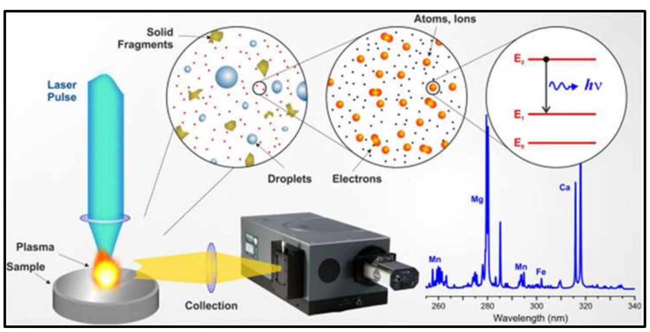
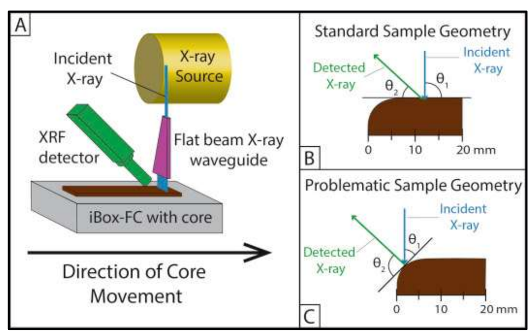
How do elemental scanning technologies work?



Advances in Laser-Induced Breakdown Spectroscopy analysis for geology: A critical review
Author links open overlay panel CécileFabre



The iBox-FC: A new containment vessel for Itrax X-ray fluorescence core-scanning of freeze cores

Braden R.B. Gregory, R. Timothy Patterson, Eduard G. Reinhardt, Jennifer M. Galloway

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Miners do it faster …

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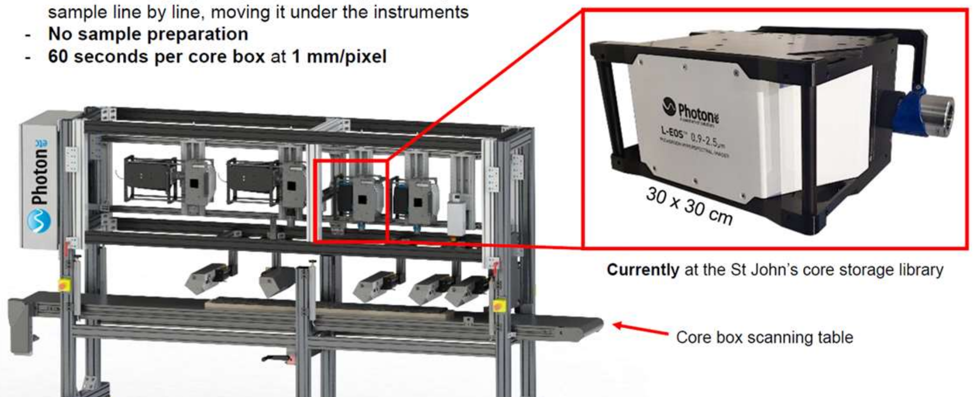
Hyperspectral instruments at CNA

- Line-scan imaging: Image is created by scanning the sample line by line, moving it under the instruments
- **No sample preparation**
- **60 seconds per core box** at **1 mm/pixel**

Photon Etc. L-EOS 0.9-2.5
SWIR Hyperspectral camera



Currently at the St John's core storage library

Philip Lypaczewski, Ph.D.
Lead Researcher - Hyperspectral Scanning (College of the North Atlantic)

Photon etc

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Miners do it faster …

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Hyperspectral Instruments at CNA

Mobile hyperspectral drill core scanning platform: **Photon Etc. nCore** system

Hyperspectral at 1mm/pixel (co-registered):

- VNIR (400-1000 nm)
- SWIR1 (1000-1600 nm)
- SWIR2 (1600-2800 nm)
- MWIR (2800-5400 nm)
- LWIR (7500 – 13000 nm)
- 3D profiler (LMI Gocator 2350)
- RGB (0.15 mm/pixel)
- **Room for additional instruments**

Spatial resolution: **1.0 mm / pixel**
Scanning time: **60 sec round trip** box-in to box-out
= **2000 m / 8 hour** shift

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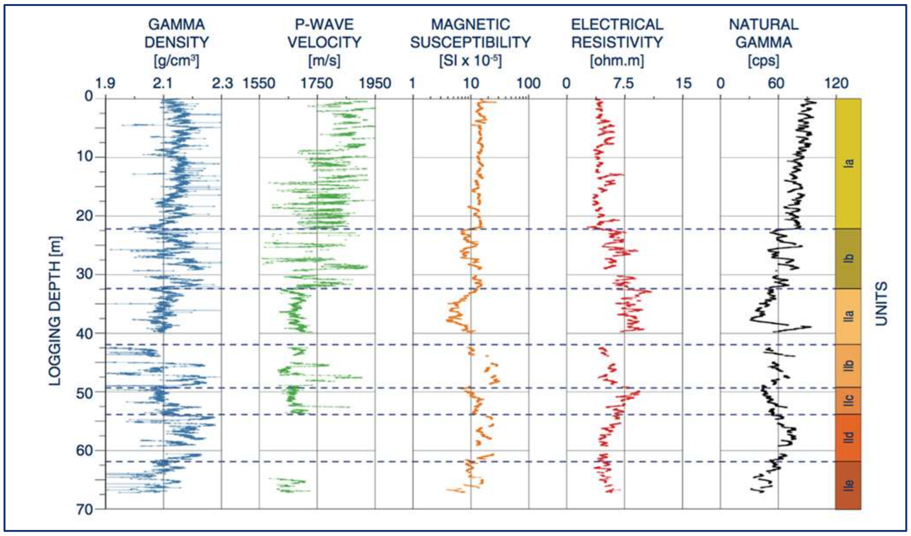
Case Study: ONDRAF/NIRAS Multi-Parameter Stratigraphy



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https://www.ondraf.be

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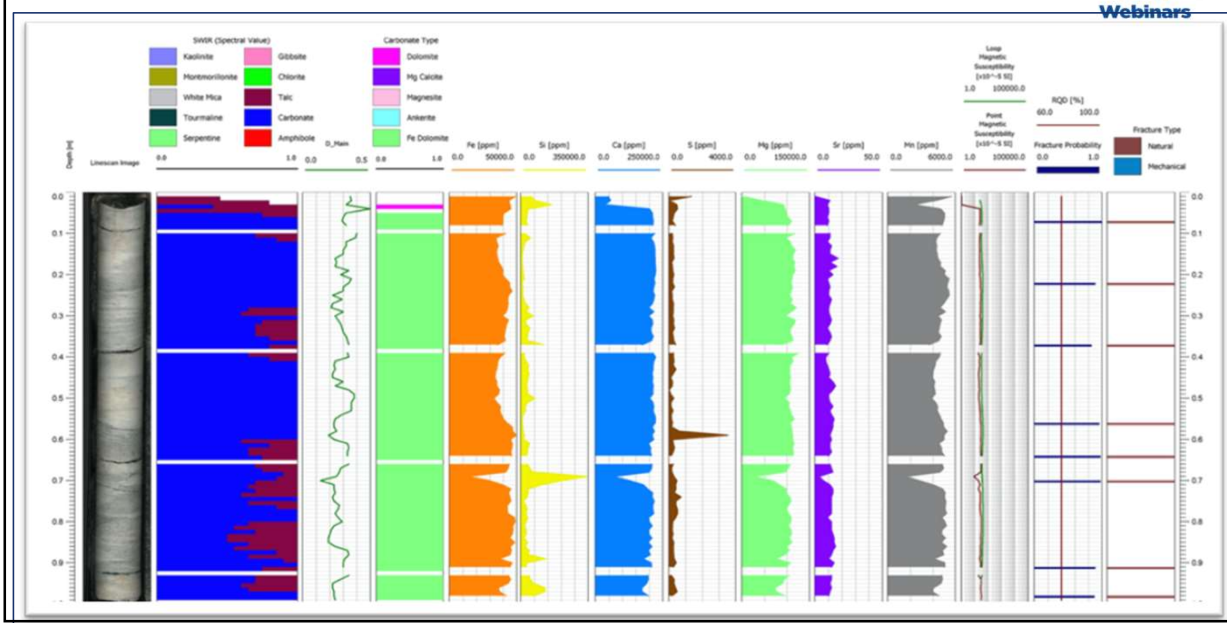
Interpretation of core chemistry & fractures



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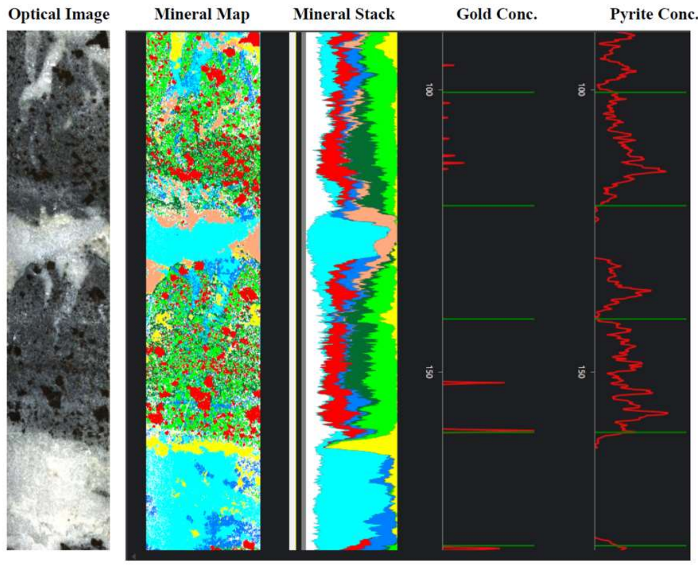
Interpretation of



LIBS

GeoTek

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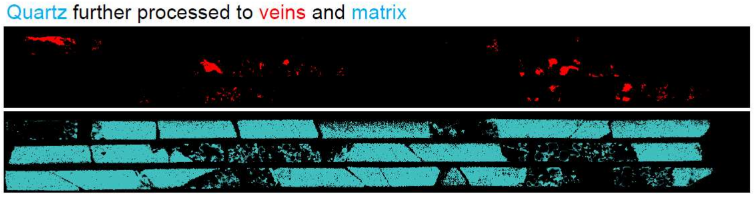
Interpretation of

Hyperspectral data output - LWIR

nCore data includes:
- **LWIR (7500-13000 nm)** - Detection of non-hydrated silicates
- Detection of quartz (silicification) and plagioclase/K-feldspars (potassic alteration)

Quartz further processed to veins and matrix



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Interpretation of

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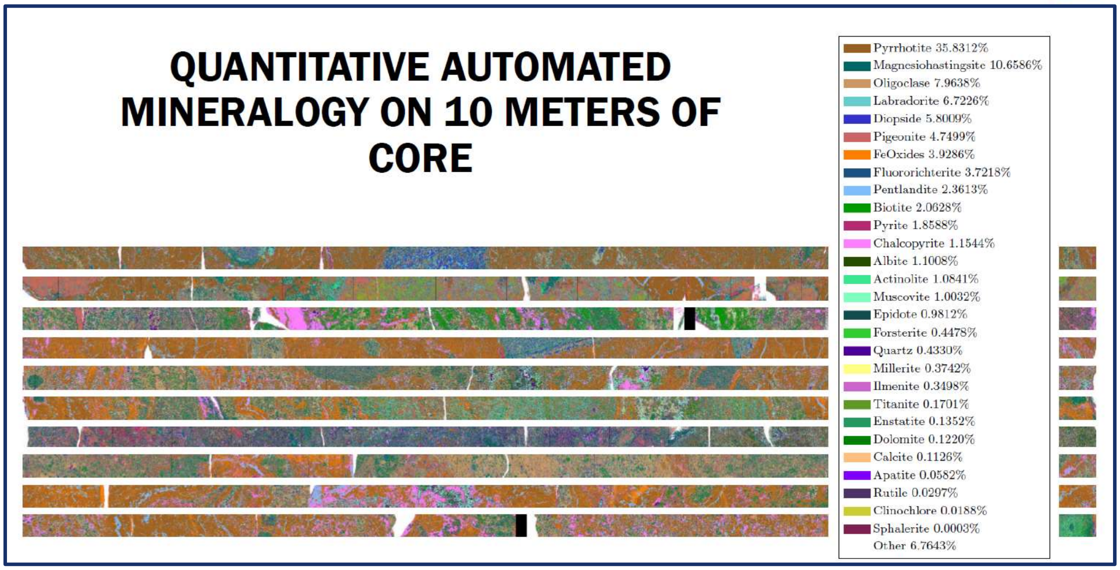

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A lot of data = A lot of opportunities

Smart Core Analysis

(SCA, SMCA, SACA …)

"Making Core Analysis Great Again"

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X-Ray Fluorescence to Mineral Assemblage

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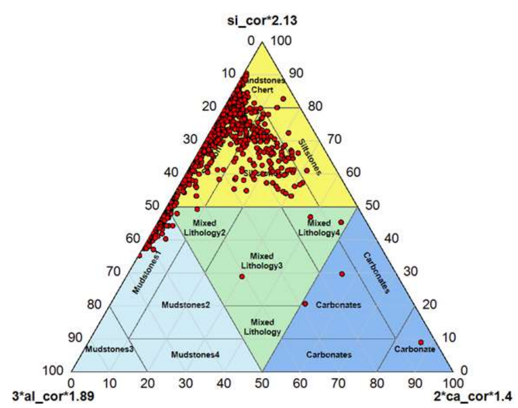

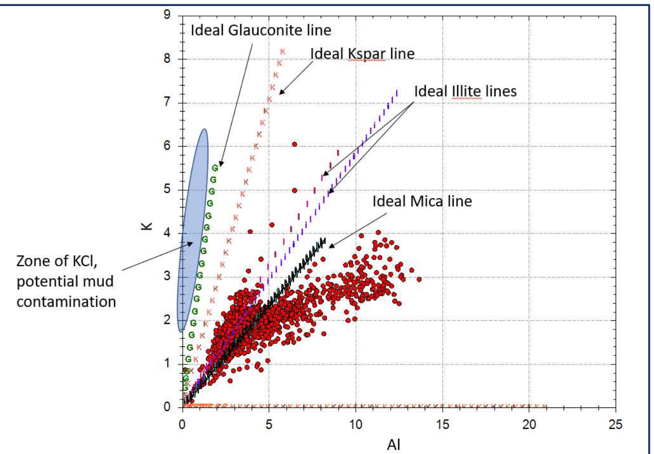

Clay/feldspar identification using K and Al

https://www.linkedin.com/in/jenniferkharrazi/

Stratum Reservoir

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Major elements and calculated mineralogy from XRF

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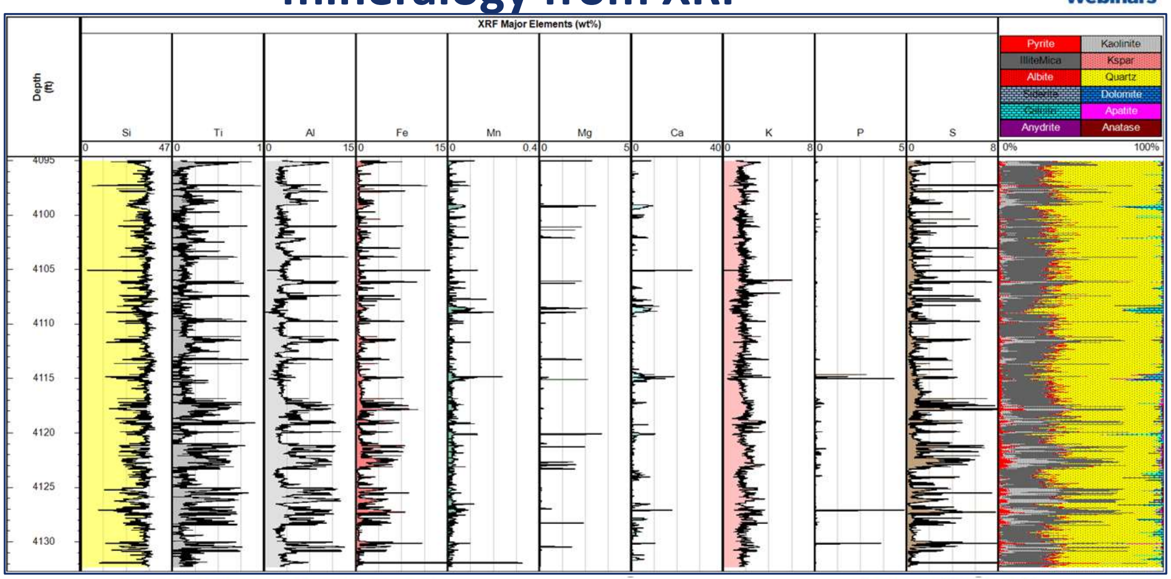

https://www.linkedin.com/in/jenniferkharrazi/

Stratum Reservoir

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MSCL Data Analysis – Domain Classifications

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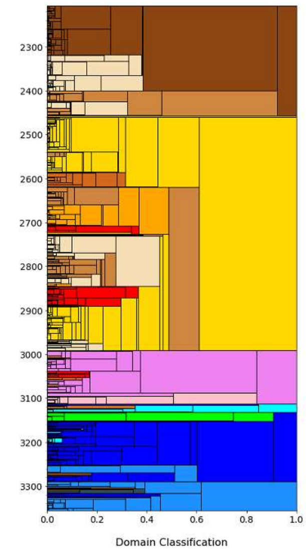
- Untrained, automated method:
  - **Detect** natural boundaries in data;
  - **Classify** data independantly of boundary information;
  - Combine boundary and classification information, creating hierarchical domains;
- Very few assumptions (data, algorithm, No. clusters).

DATA MOSAIC

Hill E J, Robertson J and Uvarova Y (2015). Multiscale hierarchical domaining and compression of drill hole data. Computers & Geosciences, 79, 47-57.
Hill E J, Uvarova Y (2018) Identifying the nature of lithogeochemical boundaries in drill holes. Journal of Geochemical Exploration 184:167–178



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MSCL Data Analysis – Domain Classifications

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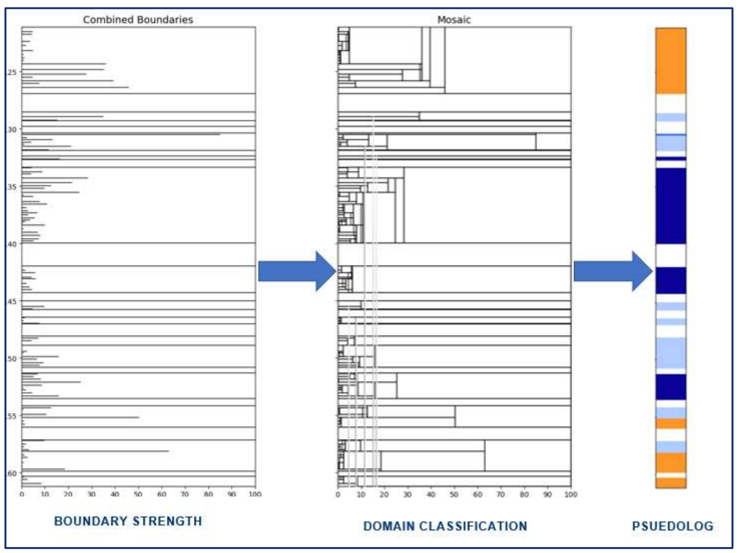
- MSCL data analysed by multiscale boundary detection using Continuous Wavelet Transform;
  - MSCL data used for analysis: **Magnetic susceptibility, electrical resistivity, natural gamma, colour (L*,a*, b*) and XRF (Ca,Si,Al,Ti,Fe,S,K,total counts);**
- Boundaries combined for multiple variables
- Domains created via multivariate tessellation
- MSCL dataset classified via K-means clustering
- Classification applied to mosaic plot
- Pseudolog generated at desired length resolution



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Case Study: Rock Core – Well 211-23-8Z (8S1) – FOUR ROCK TYPE ANALYSIS

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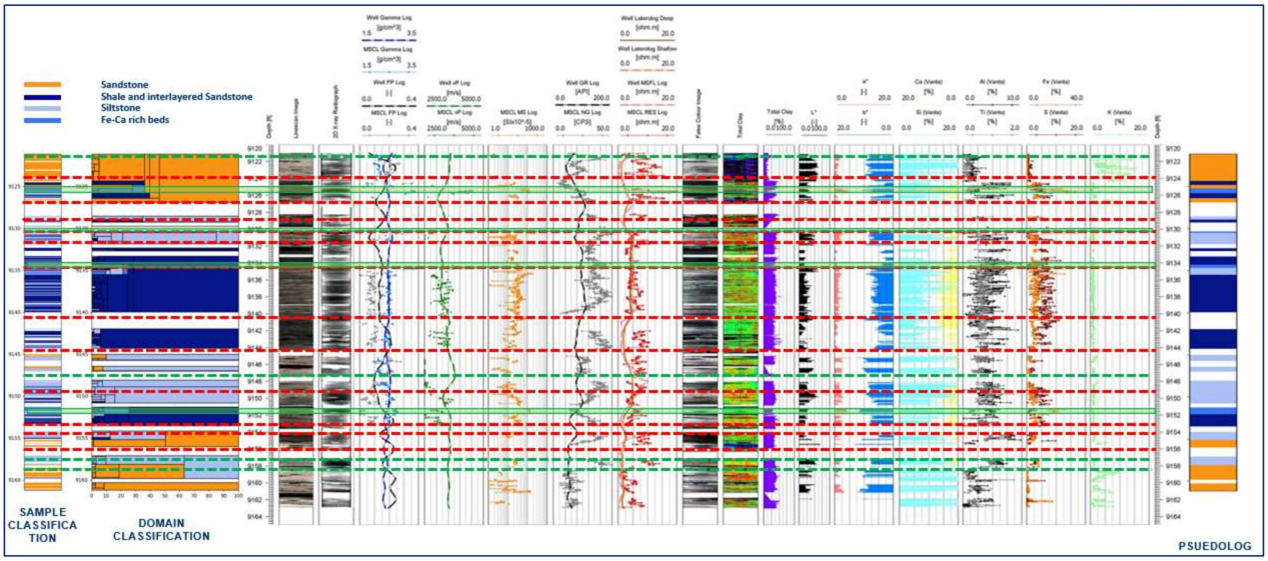

GeoTek

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Facies Identification: Unsupervised Machine Learning

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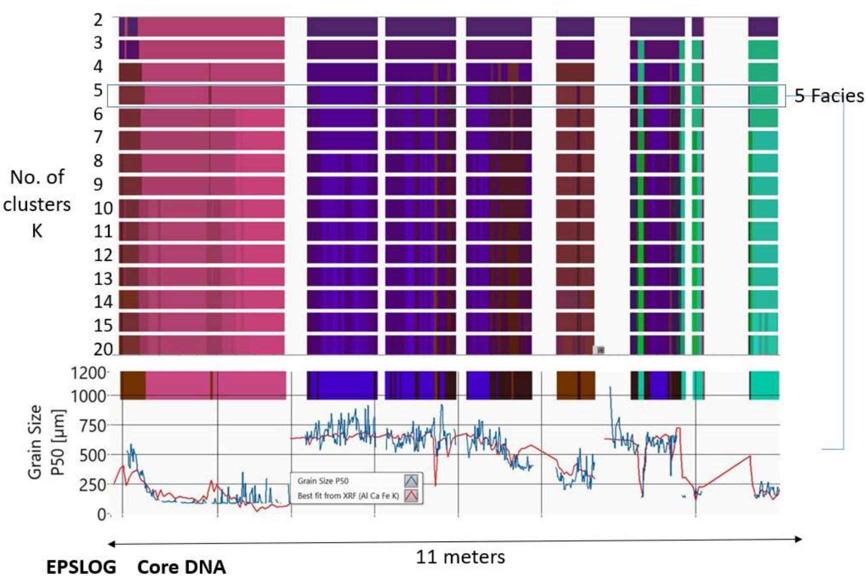
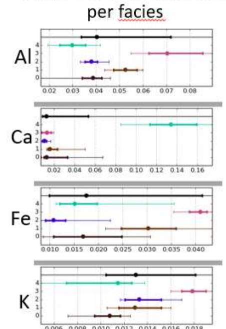


Clustering on Al Ca Fe K

Fraction of total core length

K4	K3	K2	K1	K0
11%	27%	28%	16%	18%

Elemental Concentrations per facies



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Facies Characterisation: Quantitate Values

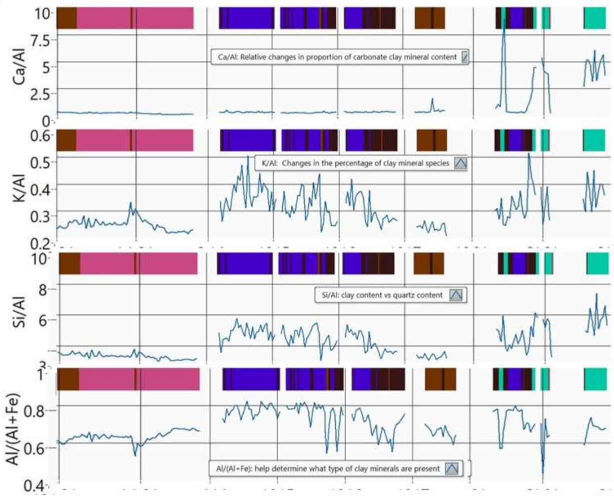
Relative changes:

carbonate/clay

Clay Mineral species

Clay /Quartz

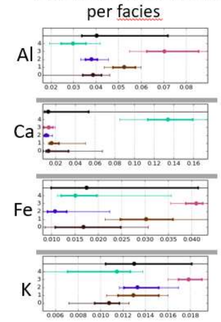
Type of clay minerals



Fraction of total core length

K4	K3	K2	K1	K0
11%	27%	28%	16%	18%

Elemental Concentrations per facies



EPSLOG Core DNA

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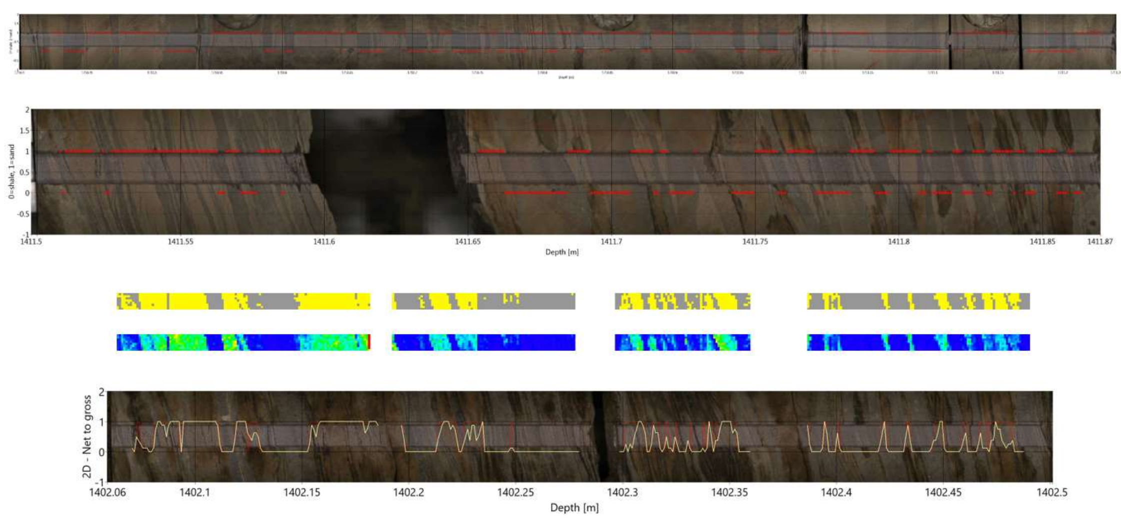
Net to Gross



EPSLOG Core DNA

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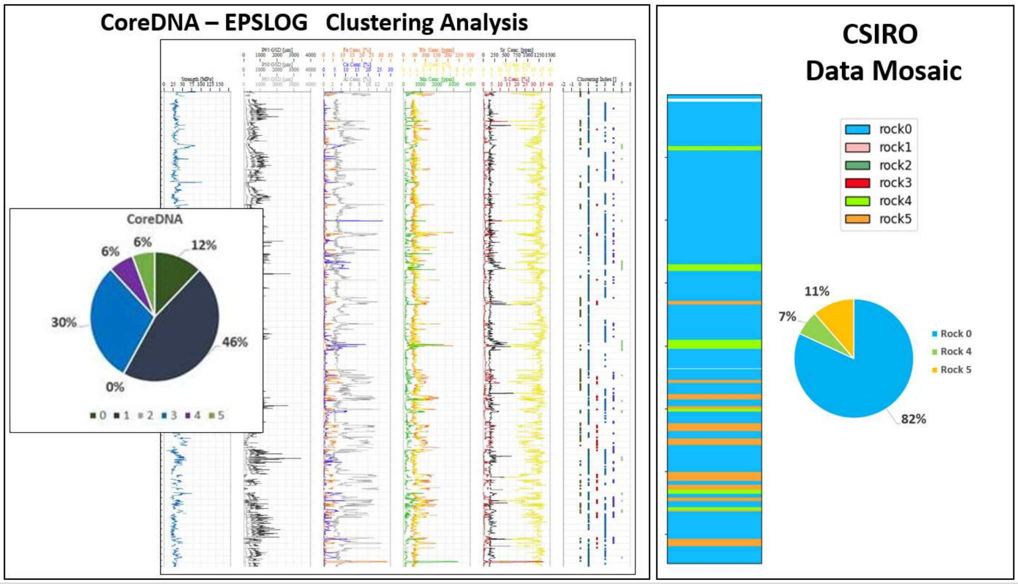
Comparative Interpretation- Example 1



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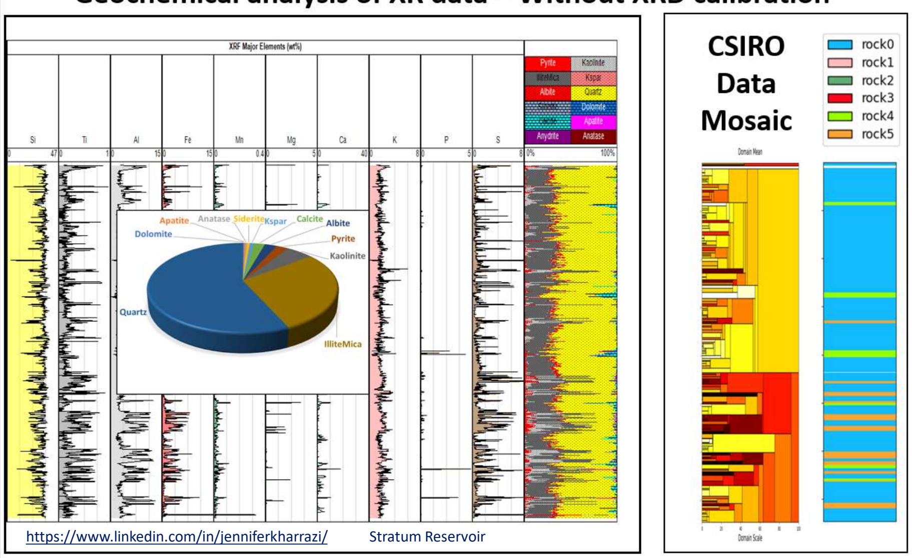
Comparative Interpretation- Example 2

Geochemical analysis of XR data – Without XRD calibration



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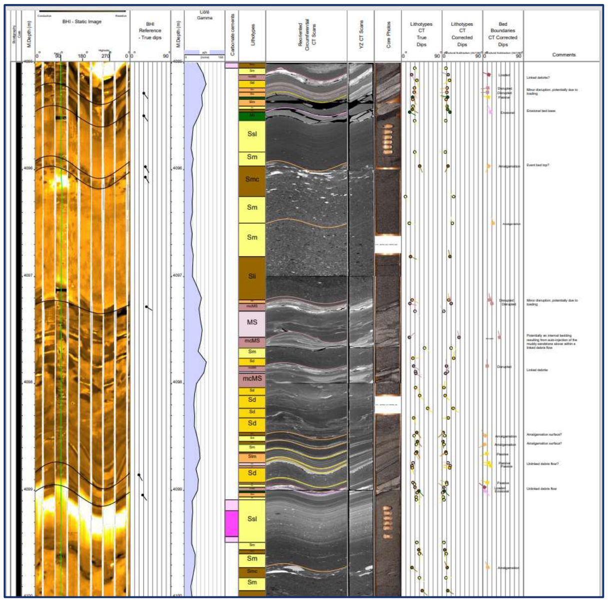
Structural analysis from BHI and X-Ray CT

Webinars



Badley Ashton & Associates Ltd

SPE International

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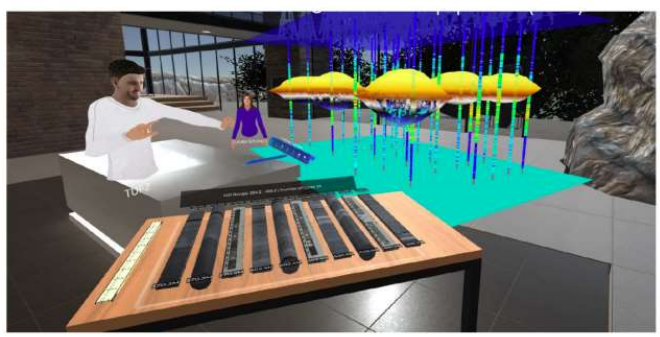
Core in Holographic Virtual Reality (VR) – Digital Core Store

Webinars

Core viewing has no easy substitute but;

- You may be too busy
- You would like to hold multi-party core workshops
- You many not have the travel budget
- You may not have the travel visa
- You would like to view the core multiple times
- You don't want to pay for the extra days of core viewing
- Your on the go and only have your tablet or smart phone
- You would like to view the core augmented with data
- You would like to see multiple wells
- You would like to see the core in geospatial context
- You would like to use the core as a teaching resource
- You have your own reasons for viewing the core at your desk



We all ❤ core!

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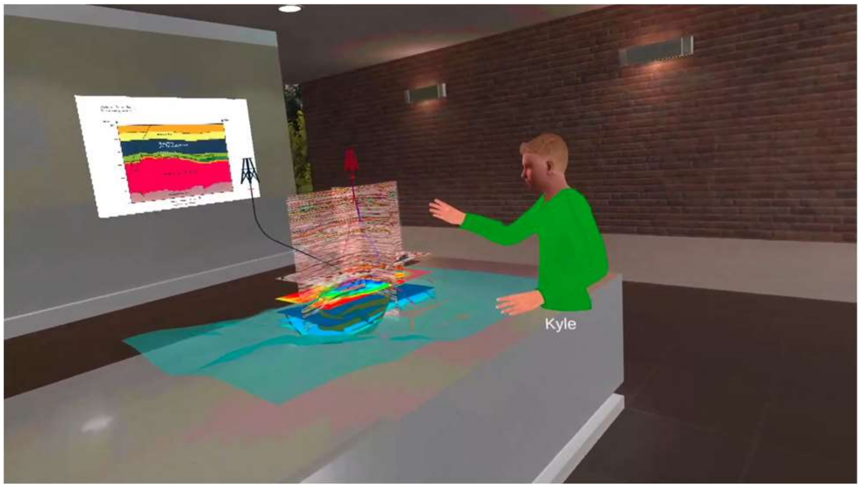
Virtual Core Table

Webinars



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Simulating lunar water

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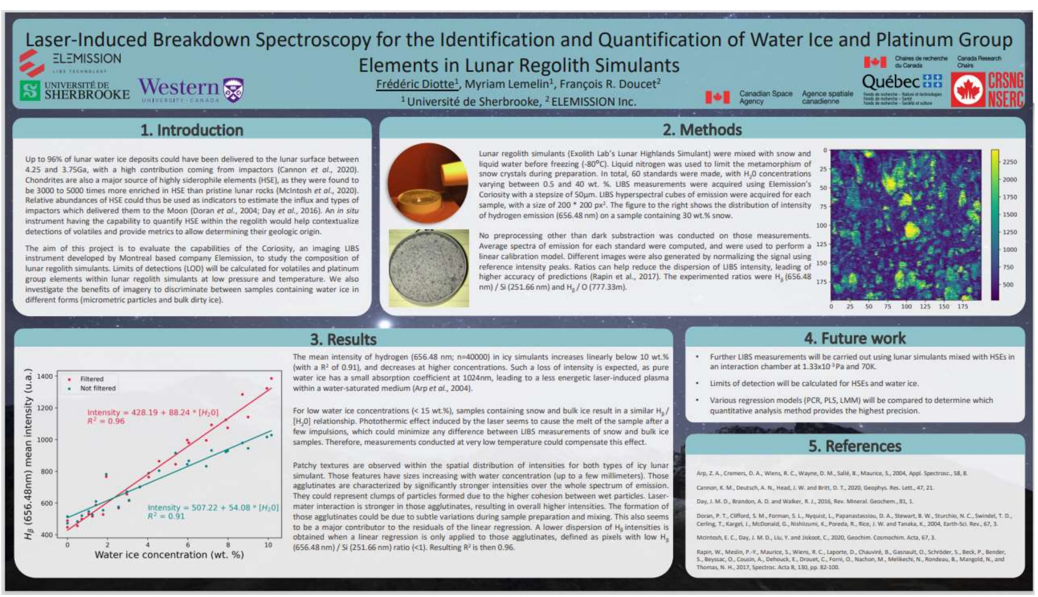

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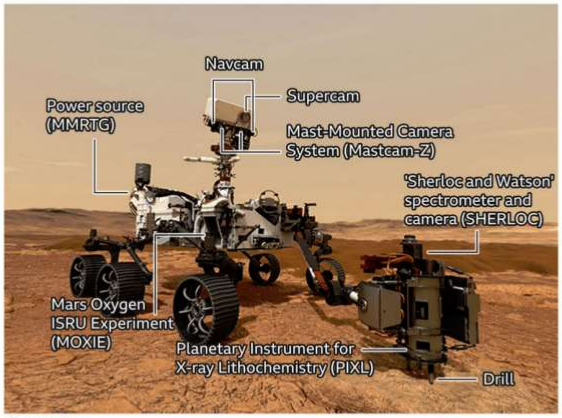
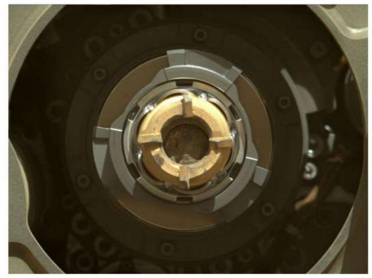
Extra-terrestrial core.
To infinity and beyond (almost)



Source: Nasa



A close-up of the drill holes Montdenier (left) and Montagnac (right)

Due back on Earth ~ 2030!

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Thank You - Questions

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