CORE ANALYSIS

Introduction For Geophysics Engineer

Muhammad Nur Ali Akbar
Petroleum Engineer

Budapest, 25 April 2022

MOLGROUP

AGENDA

- ✓ Introduction
- ✓ Overview
- ✓ What can we obtain from cuttings?
- ✓ Core analysis used for petrophysical interpretation
- ✓ The main role of core analysis in petrophysics

RULES OF THE HOUSE

NICE AND EASY

- TIMING (± 50 mins)
- Recording
- Muted your AUDIO and camera during presentation
- CHAT is available
- Question and answer after the presentation (2 sessions)

INTRODUCTION

EDUCATION

University of Miskolc, Hungary
MSc Petroleum Geoengineering (2017 – 2019)

Institut Teknologi dan Sains Bandung, Indonesia
BSc Petroleum Engineering (2010 – 2014)

WORK EXPERIENCE

Reservoir characterization experience scopes in conventional reservoirs (clastic, carbonate, naturally fractured basement) and unconventional organic-rich shale reservoir.

MOL Hungary – Petroleum Engineer (2020 - Now)
*Focused on subsurface aspects (petrophysics and reservoir engineering)

LEMIGAS – Reservoir Engineer & Petrophysicist (2017 & 2019)
*Affiliated projects with Repsol, Pertamina, Petronas, and Ophir.

LAPI ITB – Jr. Reservoir Engineer (2014-2016)
*Affiliated project with Pertamina

ABOUT PRESENTER

Selected Publication

Over 20 publications Including four peer-reviewed journals have been published and presented in various well-known international conferences of SPE, AAPG, SPWLA, EAGE, IPTC and URTeC in the USA, Asia, and Europe. The result works are available in ResearchGate, OnePetro, and Google Scholar.

- Naturally Fractured Basement Reservoir Characterization in a Mature Field **(SPE ATCE 2021, Dubai, UAE)**
- An Automated and Robust Solution of K-Means Cluster Analysis Based on Most Frequent Value Approach **(EAGE Annual 2021, Amsterdam, Netherland)**
- *New Approaches of Porosity-Permeability Estimations and Quality Factor (Q) Characterization based on Sonic Velocity, Critical Porosity, and Rock Typing.* **(SPE-ATCE 2019, Calgary, Canada)**
- *Systematic Influences of Internal Pore Structure on Compressional Sonic Velocity and Seismic Quality Factor in Sandstone* **(EAGE Annual CE 2019, London, UK)**
- *A Water Saturation Interpretation Model for Organic-Rich Shale Reservoir: A Case Study of North Sumatra Basin* **(URTeC 2018, Houston, TX, USA)**
- *Rock Typing and Shale Quality Index Method Based on Conventional Log: A Case Study for Organic-Rich Shale in the North Sumatra Basin* **(SPWLA JFES 2017, Chiba, Japan)**
- *K-Mean Cluster Analysis for Better Determining the Sweet Spot Interval of the Unconventional Organic-Rich Shale: A Case Study* **(Contemporary Trends in Geoscience Journal vol. 7(2), Poland)**
- *Estimation of Fluid-Fluid Contact and the Transition Zone: A Case Study of Low Contrast Resistivity Zones.* **(IPTC 2016, Bangkok, Thailand)**
- ....

AWARDS

Winning more than **14 international and national** competitions mainly in Asia and Europe region for petroleum engineering and geoscience specializations.

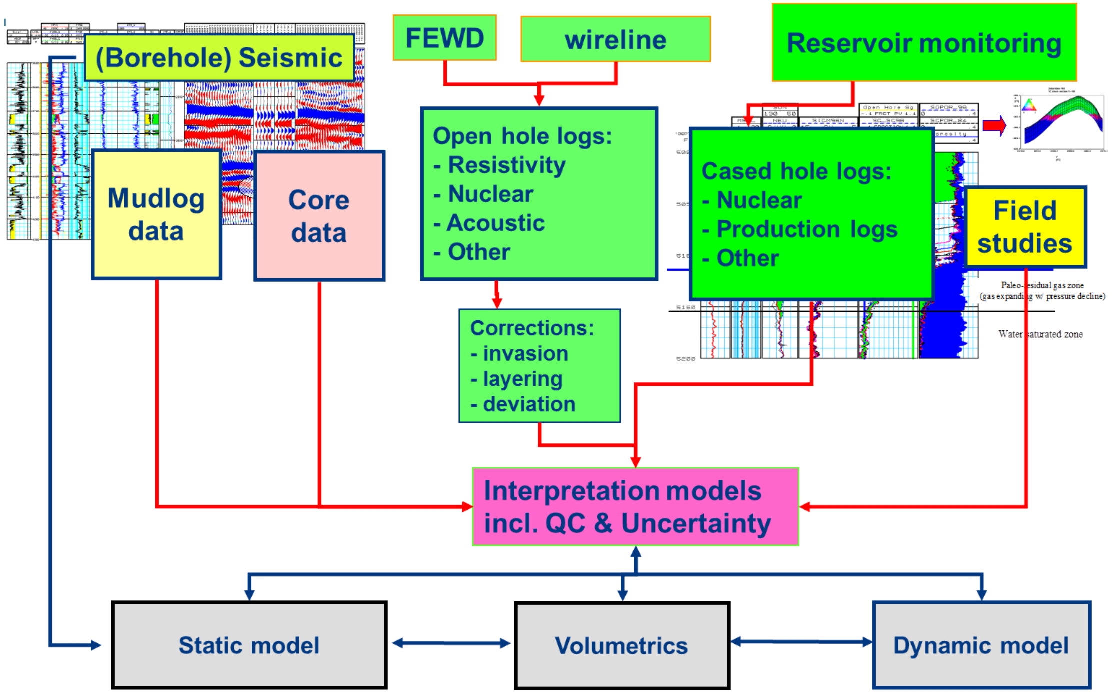
Competitions:

- **3rd place of World Championship SPE ATCE Student Paper Contest, Canada.**
- **1st Place SPE Student paper contest Europe region 2019, Poland.**
- 1st Place ISZA 2019 (Meeting of Young Geoscientist), Hungary.
- 1st Place Petro-tournament SPE ASEC 2019, Croatia.
- 1st Place paper contest at 11th Geosymposium of Young Researchers „Silesia 2018, Poland.
- 1st Place the Scientific Research Conference of the University of Miskolc (TDK), Hungary
- 3rd Place Scientific Poster at the SPE ASEC 2019, Croatia.

Special Honors:

- **Csokas Janos Award – Article of the year in Hungary 2020**
- Academic Honorary Medal "GOLD" 2019 University of Miskolc
- The Best Young Geoscientist 2019 in Hungary by MGE
- Best presenter awards from Geo-Log Kft in ISZA 2019.
- Best presenter awards by OTDK XXXIV for Physics, Mathematics, and Earth Science Sections

Petrophysical Scene



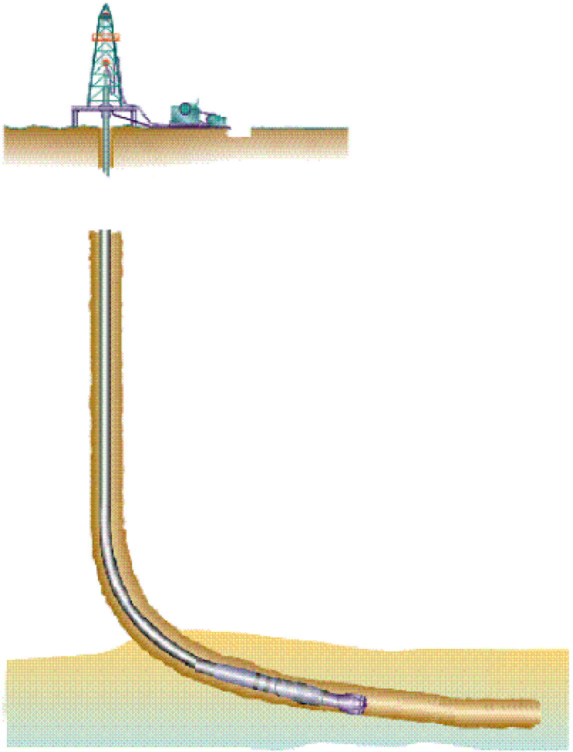
- Drilling Data
  - Mud Logging (cuttings, shows…)
  - ***Coring (drill core / sidewall samples)***
- Log Data
  - ***Open Hole Logs (wireline / while drilling)***
  - Cased Hole Logs

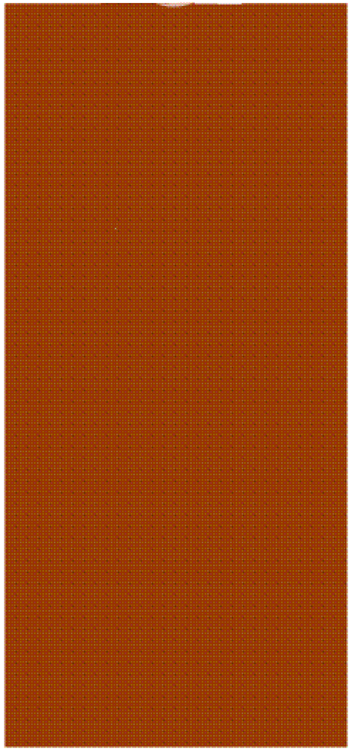
\+

- Other supplementary data (well test data, borehole seismic, offset wells, field studies, prior evaluation reports, FDP etc.)

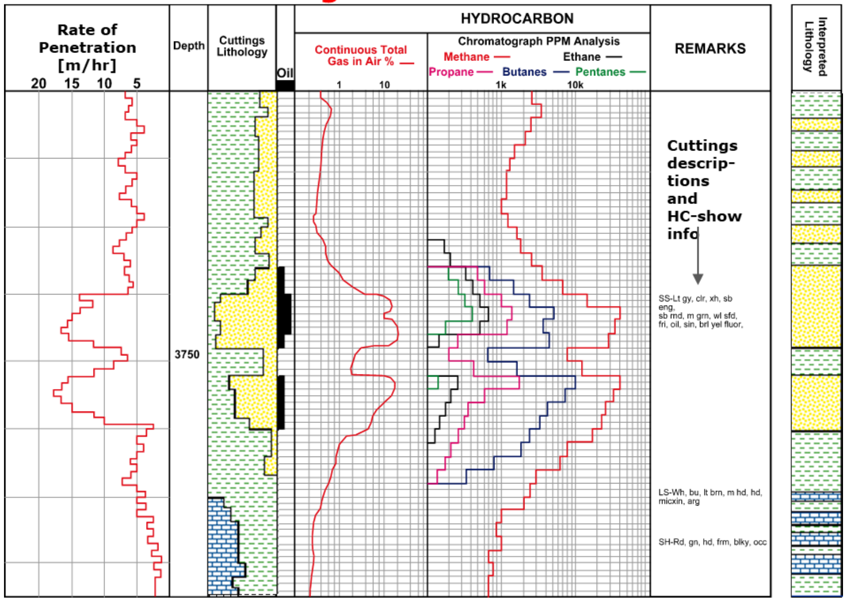
Petrophysical Evaluation

Mud Logging - Introduction





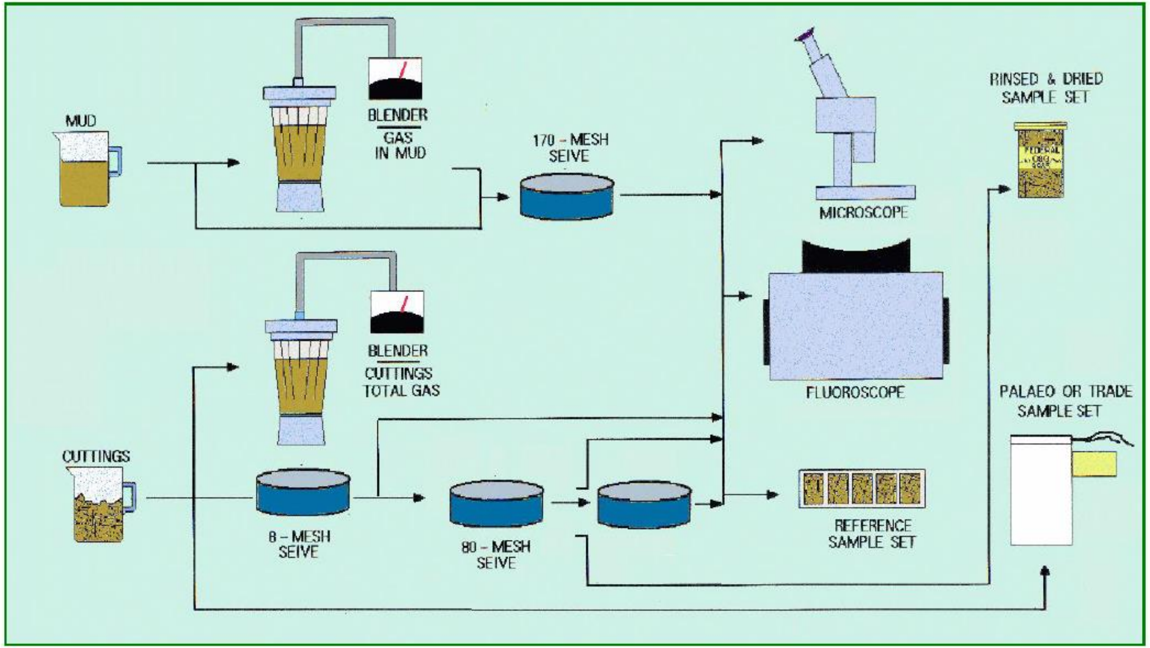
Mudlog from the well site



It’s value in evaluation should not be underestimated

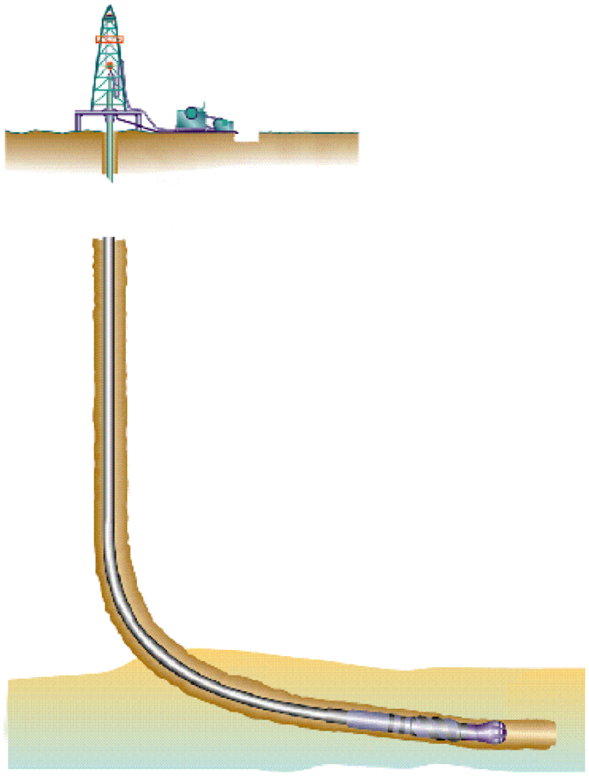
planned vs. actual
planning of operations
over-pressures
“weird” minerals
etc.

Mud Logging - Introduction



- Rock type and lithological composition
- Color
- Hardness (induration)
- Grain size
- Grain shape
- Sorting
- Luster
- Cementation or matrix
- Sedimentary structures
- Porosity
- Hydrocarbon show
- Stain
- Odor
- Fluorescence
- Cut
- Gas (total and petroleum vapor)

Mud Logging - Limitation



- ❑ Depth accuracy of ± 5 meters

The cuttings are transported to surface by mud flow which varies depending upon the volume of annulus and circulation rate (lag time).

- ❑ Rock fragments from various depths are mixed when they reach the surface.

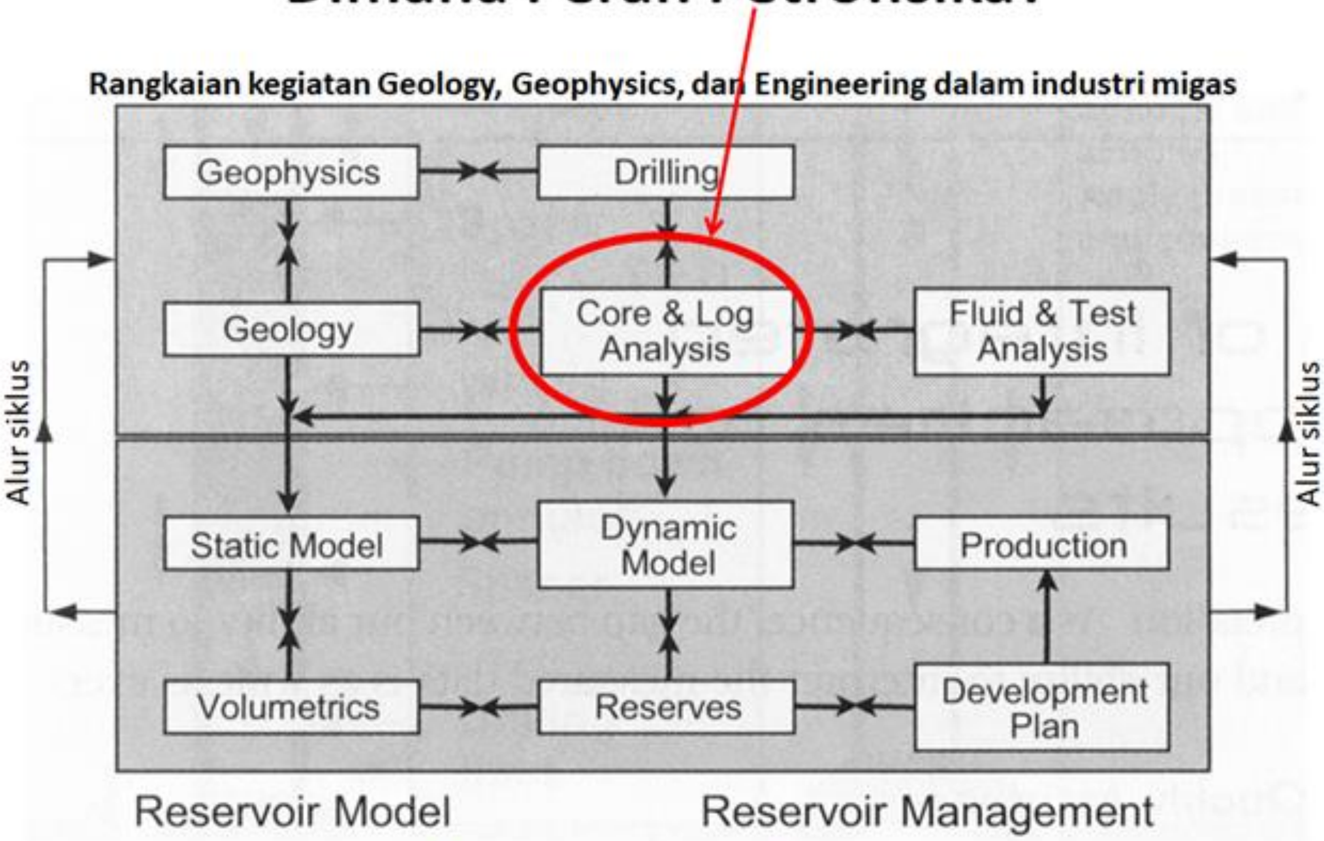
The rate of transportation of rock cuttings also depends upon their size and density resulting in mixing of cuttings from various depths.

- ❑ Unstable Shales contaminate the rock cuttings

The caving shales higher up the wellbore contaminate the cuttings from the lower depths.

Dimana Peran Petrofisika?

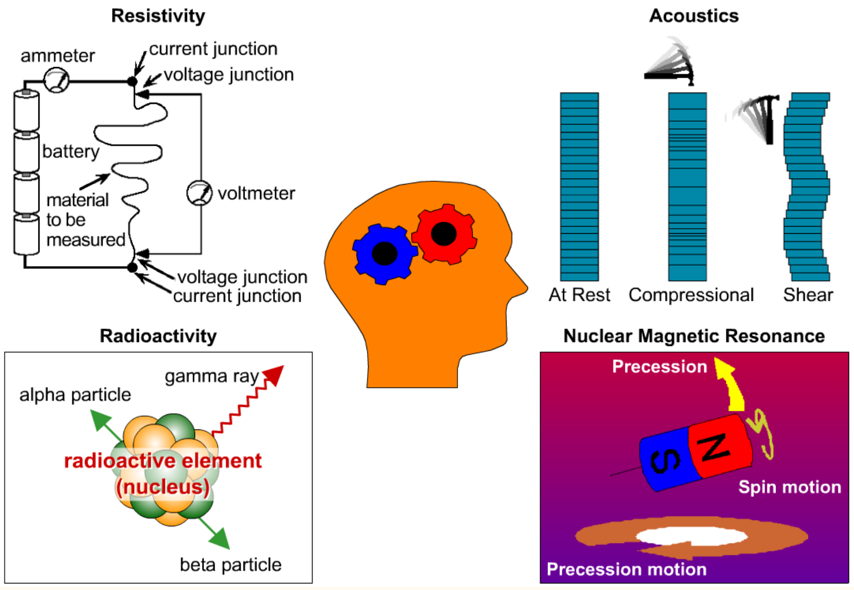
Rangkaian kegiatan Geology, Geophysics, dan Engineering dalam industri migas



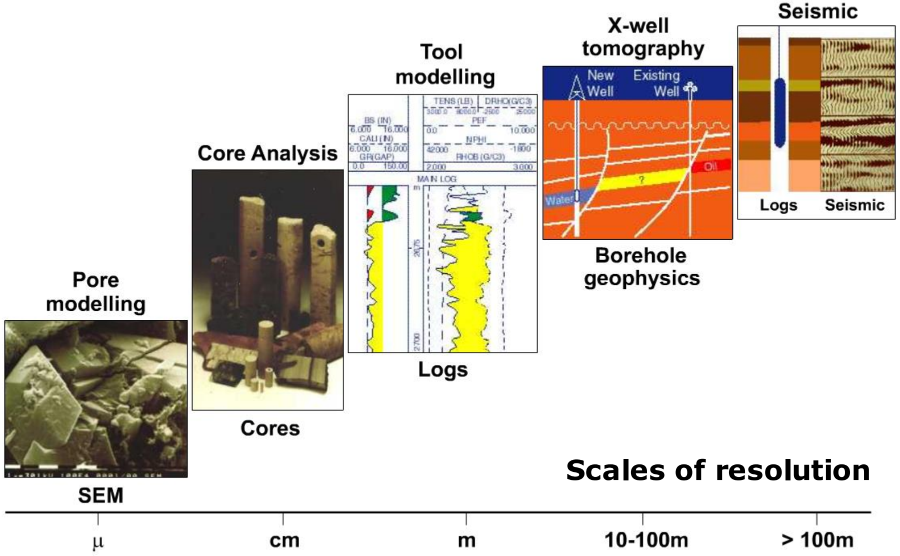
(Pemodelan) ⟷ **(Pengelolaan)**

What is Petrophysics?

Petrophysical Measurement



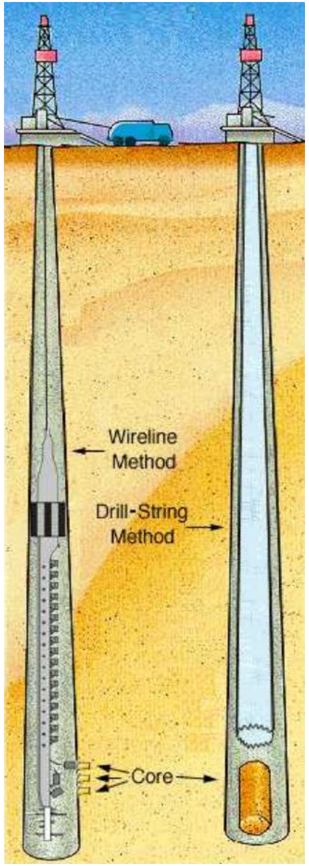
Scale

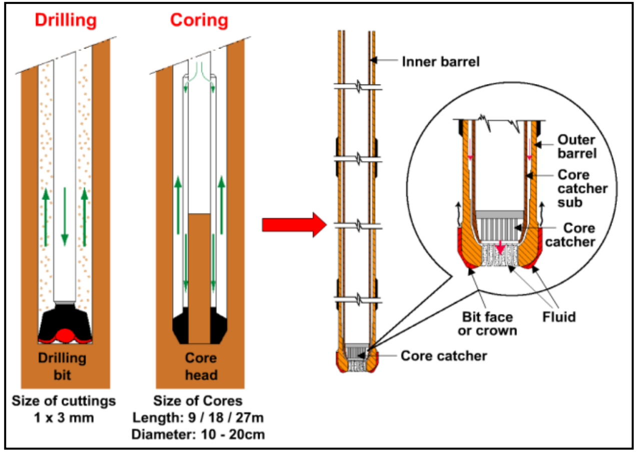


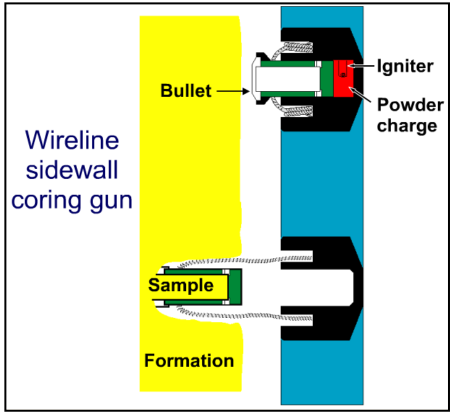
Properties

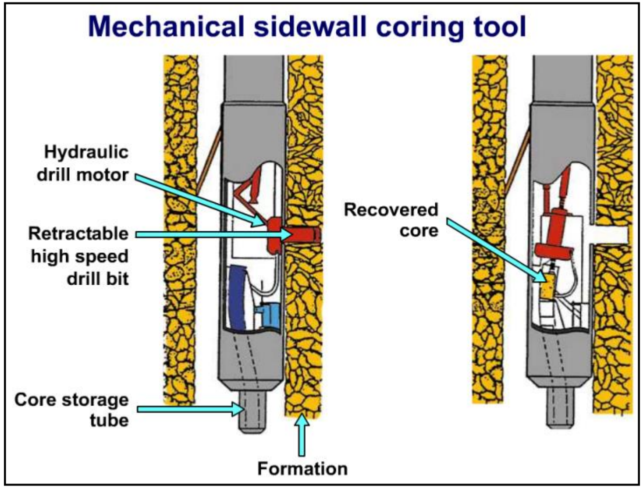
porosity, permeability, grain density, oil saturation, etc.

How the cores are taken?









What Information that you can obtained from Core?

Slabbed Core

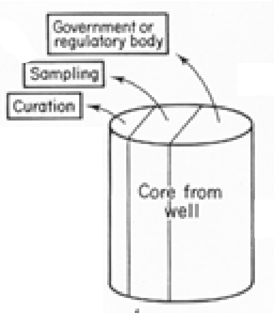
- ✓ Photograph
- ✓ Sedimentology
- ✓ Lithology
- ✓ Stratigraphy

Thin Section

- ✓ Detail Pore Structure
- ✓ Diagenesis
- ✓ Porosity Type
- ✓ Environmental evidence

Small Sample

- ✓ Grain Size Distribution
- ✓ Mineral analysis
- ✓ X-ray and SEM analysis
- ✓ Bio-dating and association



Calibration of Log Interpretation

Routine Core Analysis

- ✓ Porosity
- ✓ Permeability
- ✓ Grain Density
- ✓ As-received saturation

Special Core Analysis

- ✓ Capillary Pressure
- ✓ Relative Permeability
- ✓ Electrical Properties
- ✓ Acoustic Properties
- ✓ Compressive Properties
- ✓ Clay chemistry effects
- ✓ Specific Test

Advance Core Analysis

- ✓ NMR
- ✓ Digital Rock Physics
- ✓ Organic content and maturation

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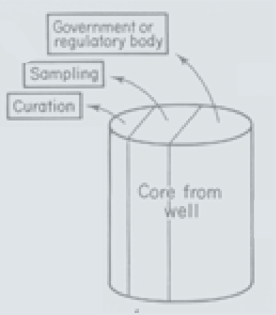

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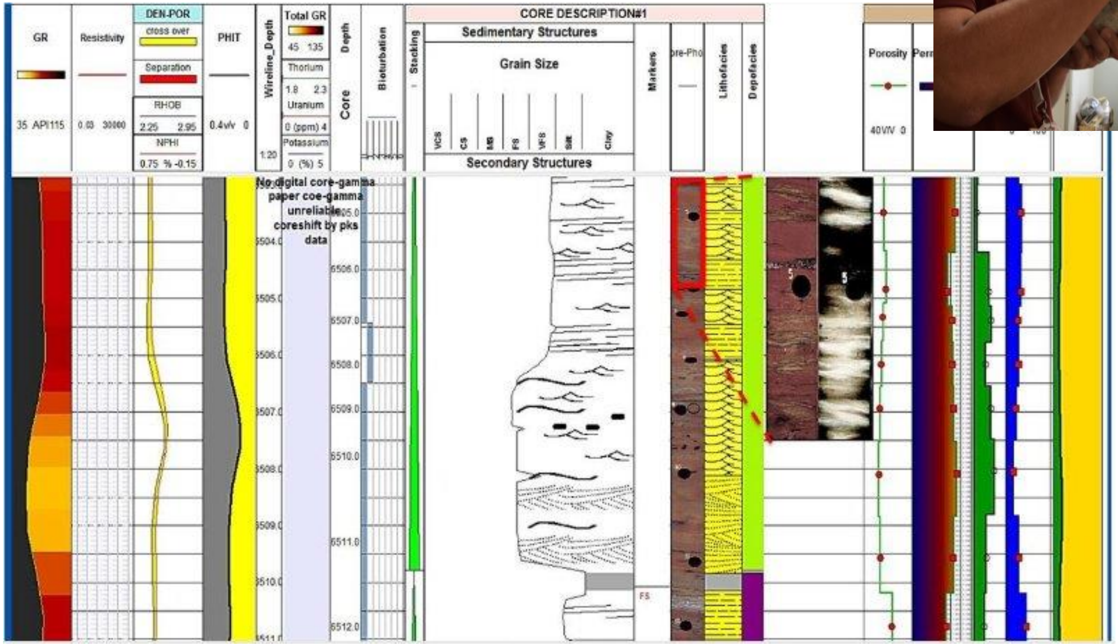
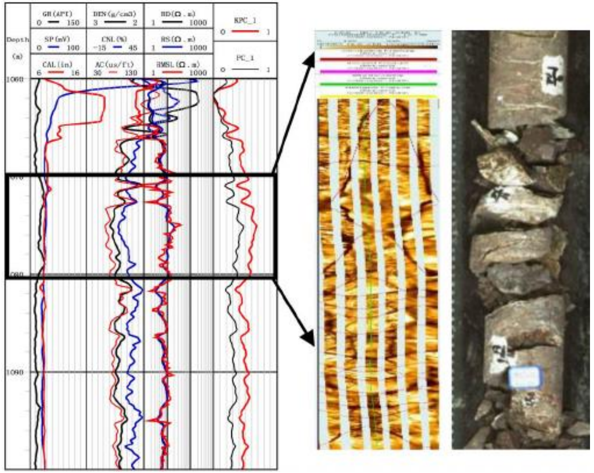
Slabbed Core

- ✓ Photograph
- ✓ Sedimentology
- ✓ Lithology
- ✓ Stratigraphy
- ✓ Testing
- ✓ Taste and Lick





Slabbed Core

- ✓ Photograph
- ✓ Sedimentology
- ✓ Lithology & structure
- ✓ Stratigraphy

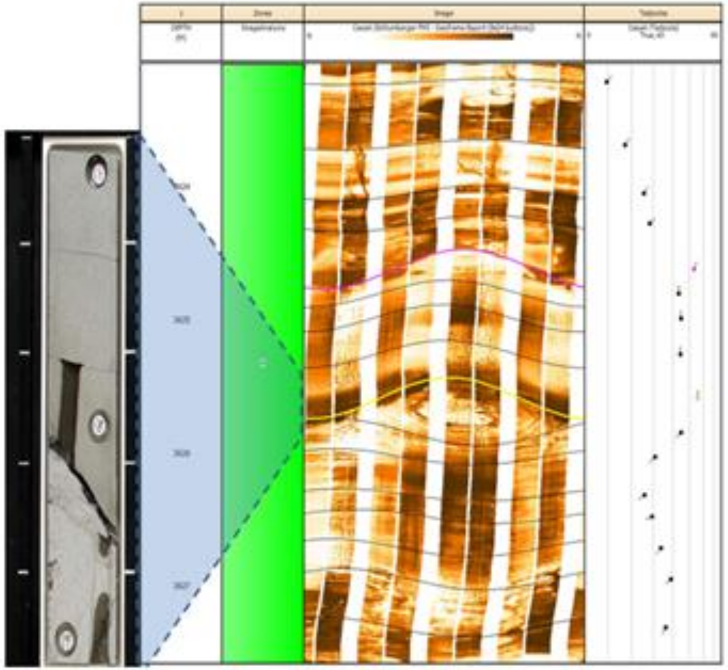


Figure 18. FMI image log with defined fault zone (yellow marked) together with core photo of the zone. Relative azimuthal direction of the hanging wall and foot wall indicate a trust fault movement type at this interval. (Core photo unit is 10cm and image log scale 1/20)

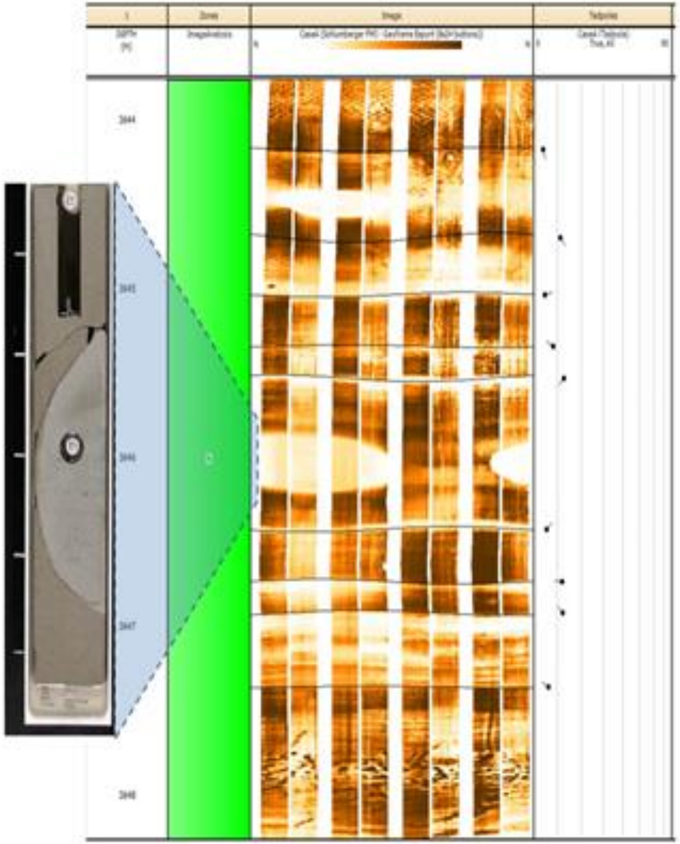


Figure 19. FMI image log with calcite cemented nodule. Image log shows that the nodule has not been detected by all image tool pads as can also be seen in the core photo. Note the possible bioturbation pattern in the bottom of the image log. (Core photo unit is 10cm and image log scale 1/20)

What Information that you can obtained from Core?

Slabbed Core

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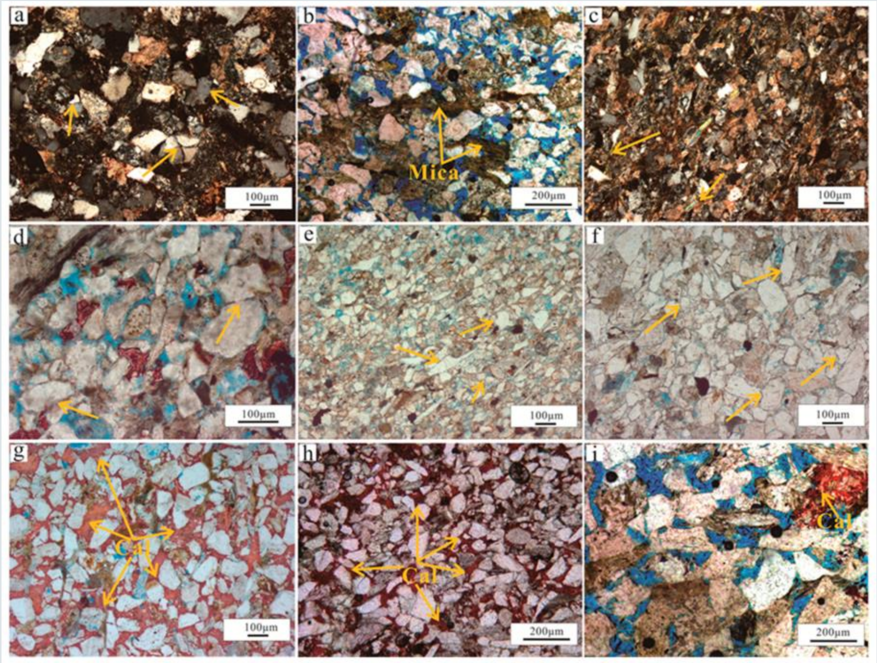
Thin Section

- ✓ Detail Pore Structure
- ✓ Diagenesis
- ✓ Porosity Type
- ✓ Environmental evidence

Small Sample

- ✓ Grain Size Distribution
- ✓ Mineral analysis
- ✓ X-ray and SEM analysis
- ✓ Bio-dating and association



BOTTOM 2098.7 m 2099.7 m 2100.7 m 2101.7 m 2102.7 m 2103.7 m

Calibration of Log Interpretation

Routine Core Analysis

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Special Core Analysis

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Advance Core Analysis

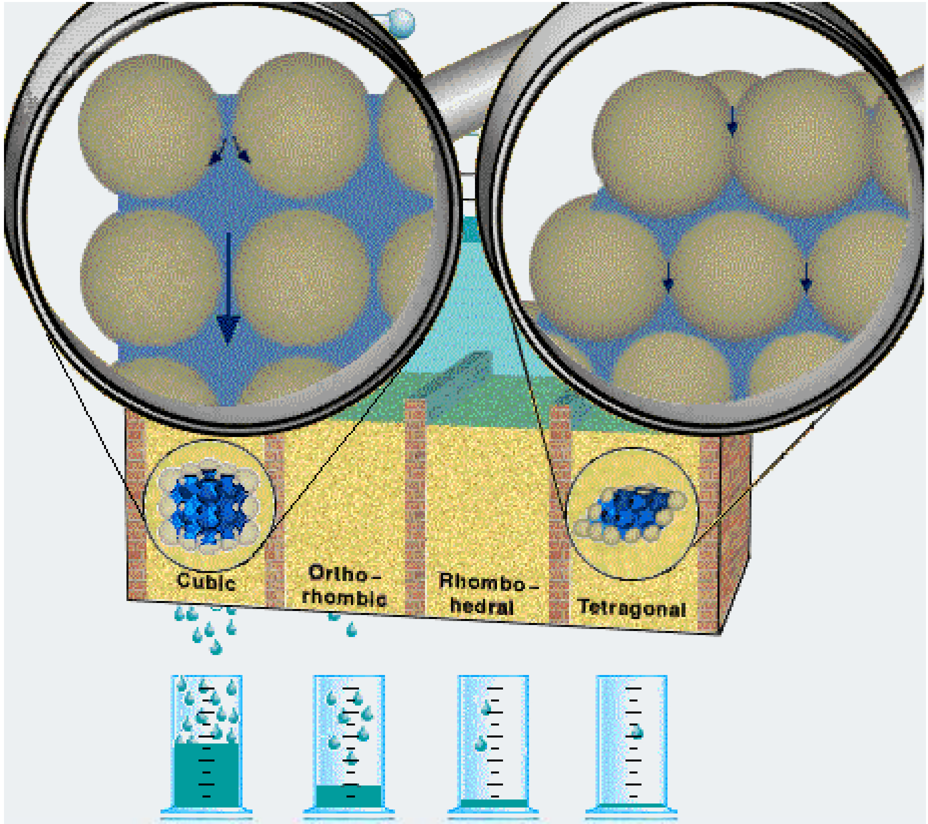
- ✓ NMR
- ✓ Digital Rock Physics
- ✓ Rock Mechanics
- ✓ Organic content and maturation

Thin Section

- ✓ Detail Pore Structure
- ✓ Diagenesis
- ✓ Porosity Type
- ✓ Environmental evidence

Pore size distribution, **packing,** grain size, sorting, porosity, and mineral abundances, fabric, rock classification, porosity varieties and abundances.

Determination of shale volume, shale distribution, porosity varieties and abundances with a discussion of diagenesis, diagenetic sequence, porosity origins and development, controls on porosity and permeability. Point count data is presented in tabular form with colour photomicrographs accompanied by detailed descriptions.



Packing

- The permeability of a formation varies according to its packing
- The packing can form different structures (cubic, tetragonal, etc.)
- It can also be poorly sorted grain packing in which the sediments have varying grain size

Thin Section

- ✓ Detail Pore Structure
- ✓ Diagenesis
- ✓ Porosity Type
- ✓ Environmental evidence

Pore size distribution, packing, **grain size,** sorting, porosity, and mineral abundances, fabric, rock classification, porosity varieties and abundances.

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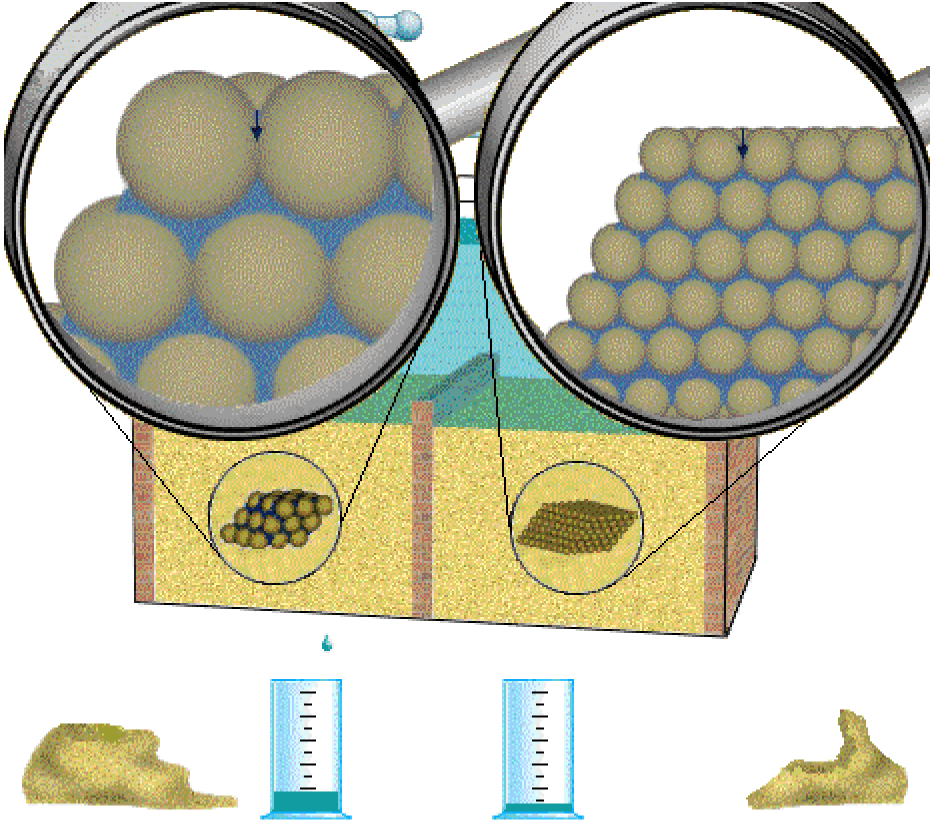


Grain size

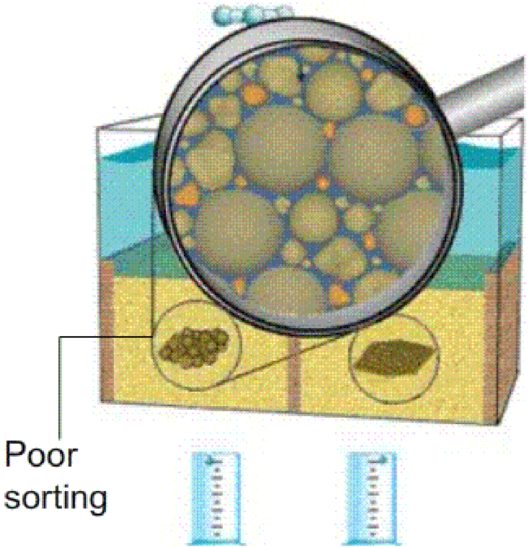
- The permeability of a formation varies according to its grain size
- Porosity is independent of grain size!
- Larger the grain size, greater the permeability

Thin Section

- ✓ Detail Pore Structure
- ✓ Diagenesis
- ✓ Porosity Type
- ✓ Environmental evidence

Pore size distribution, packing, grain size, **sorting**, porosity, and mineral abundances, fabric, rock classification, porosity varieties and abundances.

Determination of shale volume, shale distribution, porosity varieties and abundances with a discussion of diagenesis, diagenetic sequence, porosity origins and development, controls on porosity and permeability. Point count data is presented in tabular form with colour photomicrographs accompanied by detailed descriptions.

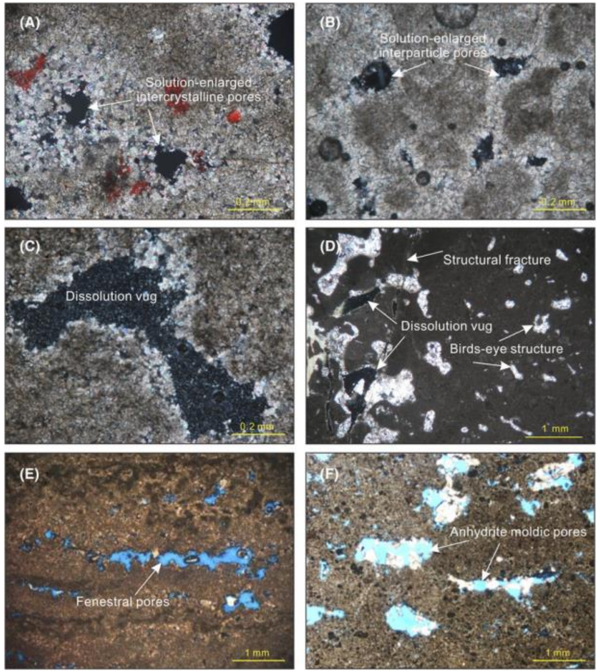


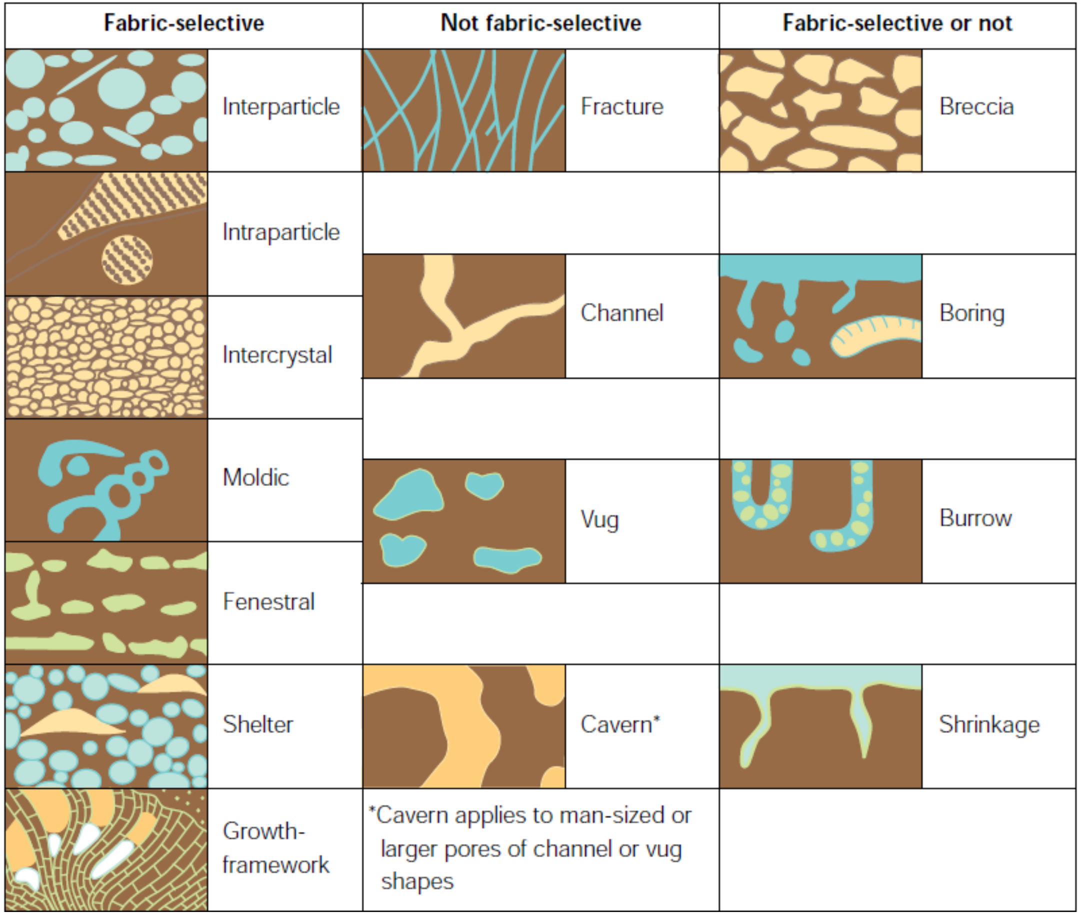
Sorting

- The permeability of a formation varies according to its sorting

Thin Section

- ✓ Detail Pore Structure
- ✓ Diagenesis
- ✓ Porosity Type
- ✓ Environmental evidence





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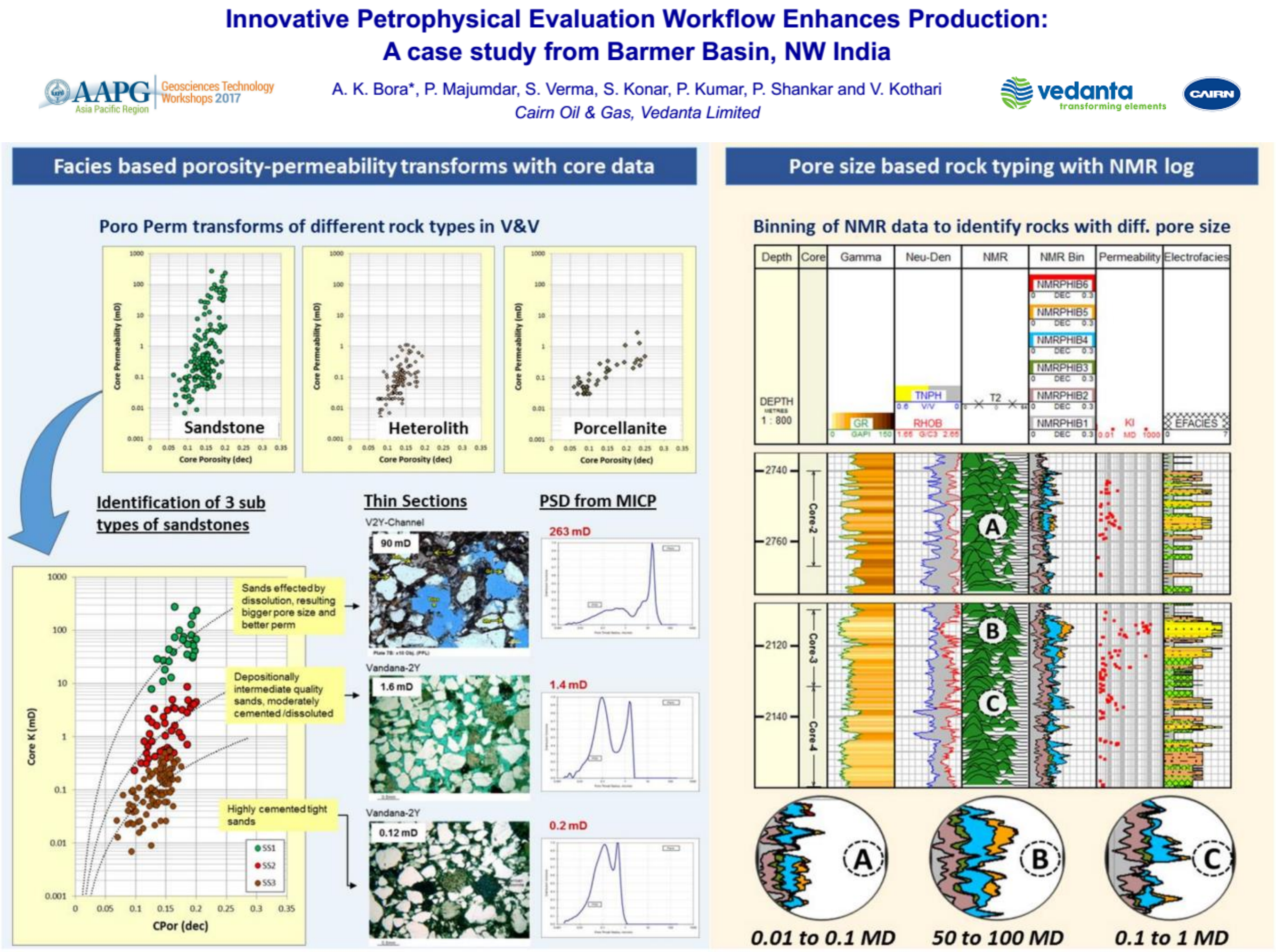

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Small Sample

- ✓ Grain Size Distribution
- ✓ Mineral analysis
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- ✓ Bio-dating and association

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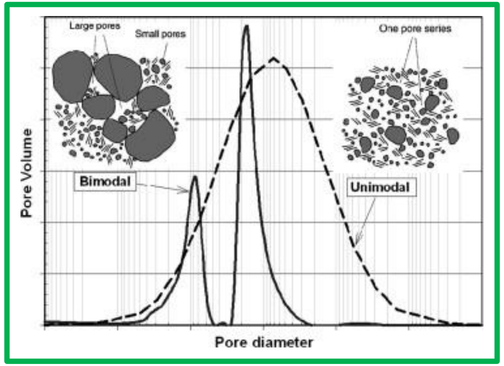

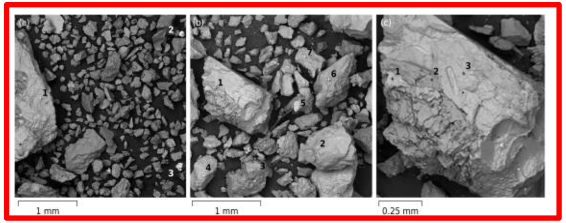

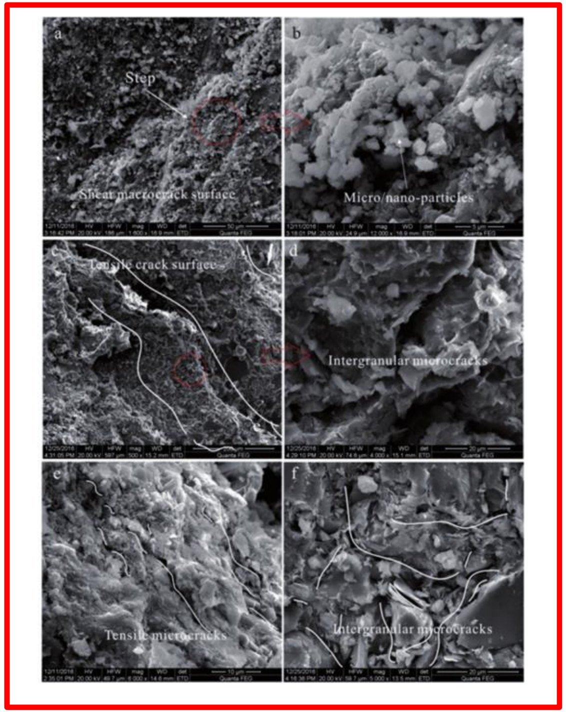

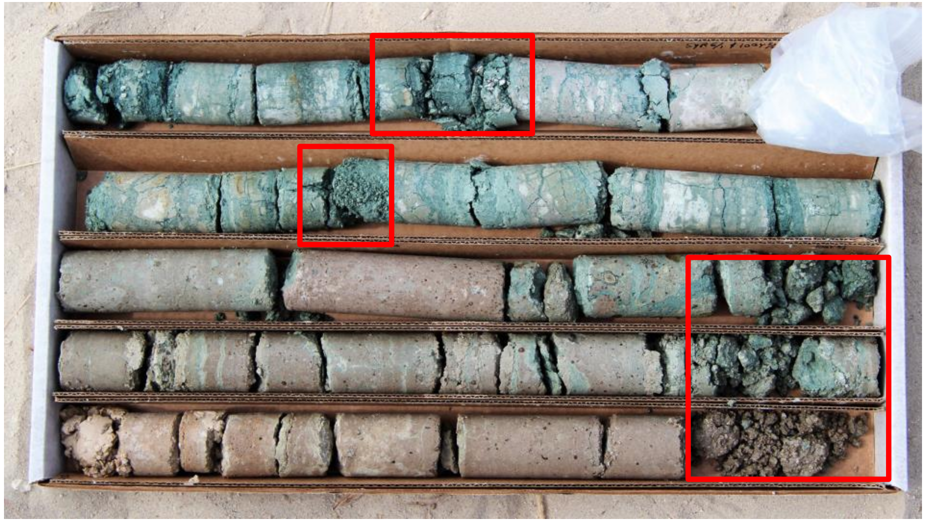

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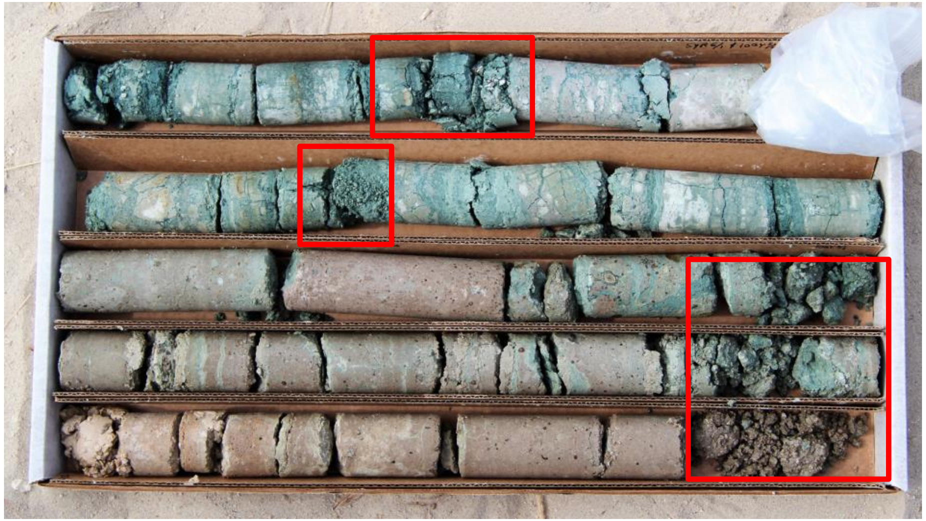
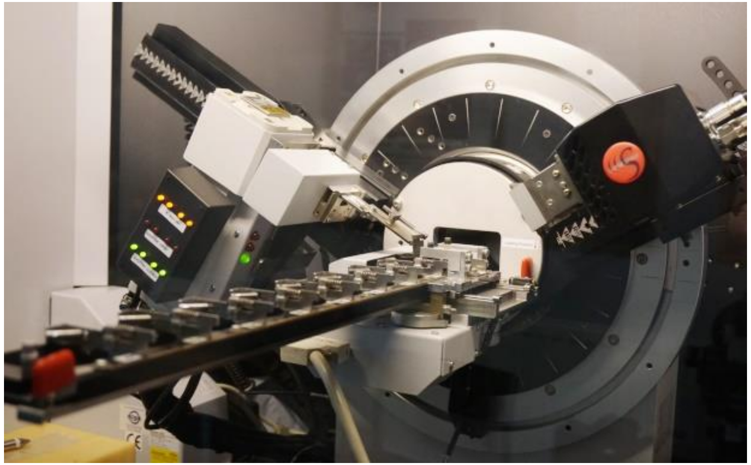
No.	WELL	SAMPLE DEPTH	ZONE	LITHOLOGY	CALCULATED WHOLE ROCK MINERAL WEIGHT PERCENT										RELATIVE CLAY ABUNDANCE				
					QTZ.	PLAG. FELD.	ALK. FELD.	CALCITE	ANKERITE	FE DOLO.	SID.	PYR.	ARAGONITE	CLAYS	ILLITE	KAOL.	SMEC.	ILL. SMEC.	CHLORITE
1	5N-63B	366.00	R2	Shale	24.1	0.9	3.4	0.0	0.0	0.2	2.6	0.3	0.0	68.5	69.60	20.70	0.0	3.0	6.7
2	5R-63B	504.00	P	Shale	32.0	2.1	3.4	0.0	0.0	0.0	3.3	0.1	0.0	59.1	54.80	30.50	0.0	14.7	0.0
3	5R-63B	623.00	K	Shale	18.0	0.0	2.4	0.0	0.0	0.0	3.2	1.0	0.0	75.4	56.20	37.40	0.0	6.4	0.0
4	5R-63B	730.00	D	Shale	26.6	1.9	0.7	1.70	0.0	0.0	0.6	1.6	0.0	66.9	44.70	44.70	0.0	10.6	0.0
5	5R-63B	754.00	D	Shale	30.1	0.0	1.1	0.0	0.0	0.0	0.6	0.6	0.0	67.6	45.00	37.90	0.0	17.1	0.0
6	3P-55B	600.00	P4	Shale	47.7	1.4	6.9	0.0	0.0	0.0	0.9	3.3	0.0	39.8	59.80	23.80	0.0	5.1	11.3
7	5G-21Z	471.70	R3	Shale	62.0	2.0	3.0	1.0	0.0	1.0	3.0	3.0	0	25	40.00	32	12	0	16
8	5G-21Z	480.75	R4	Shale	62.0	2.0	3.0	1.0	0.0	1.0	3.0	2.0	0	25	48.00	32	12	0	8





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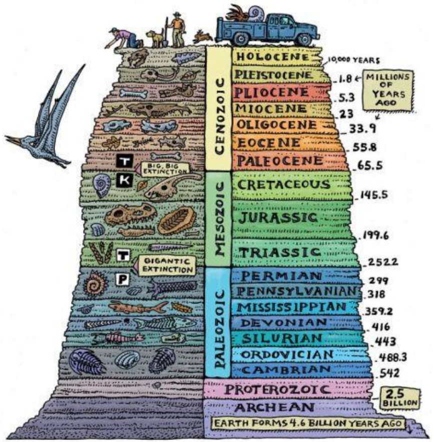

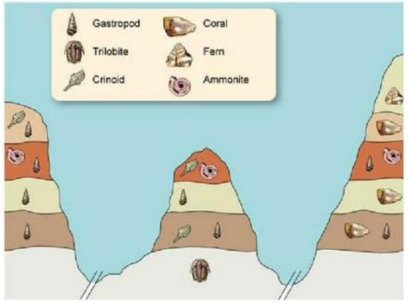

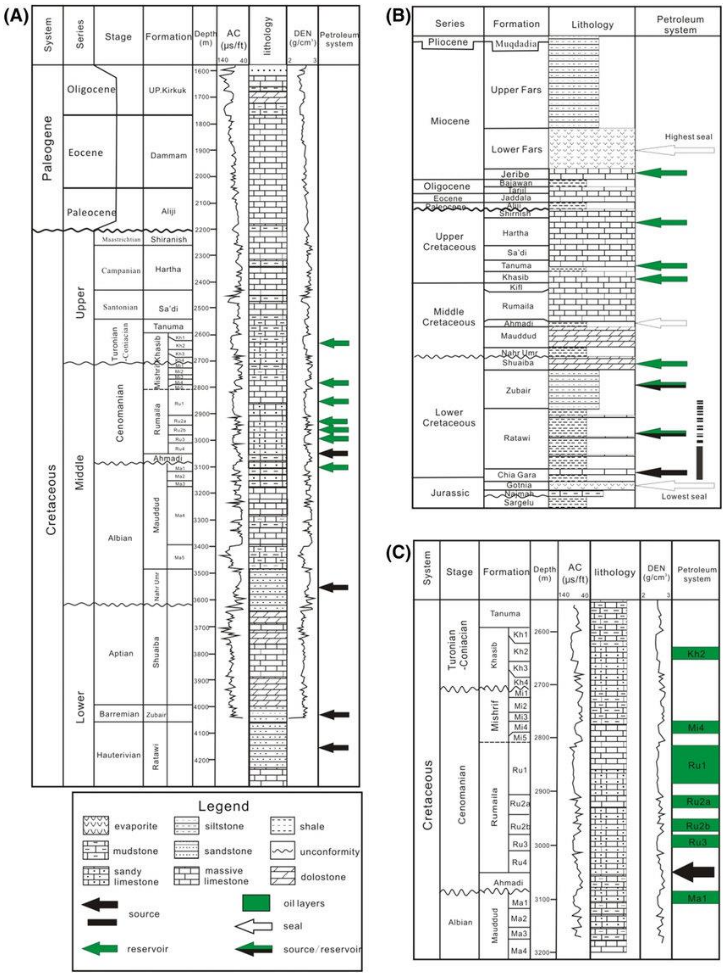

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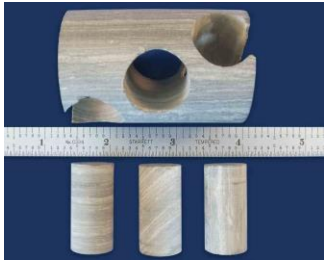
Advance Core Analysis

- ✓ NMR
- ✓ Digital Rock Physics
- ✓ Rock Mechanics
- ✓ Organic content and maturation

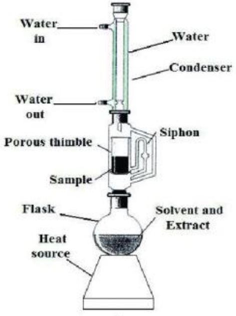
ROUTINE CORE ANALYSIS



Coring Process

↓

Cleaning and Drying



Porosity

Grain Density

Permeability

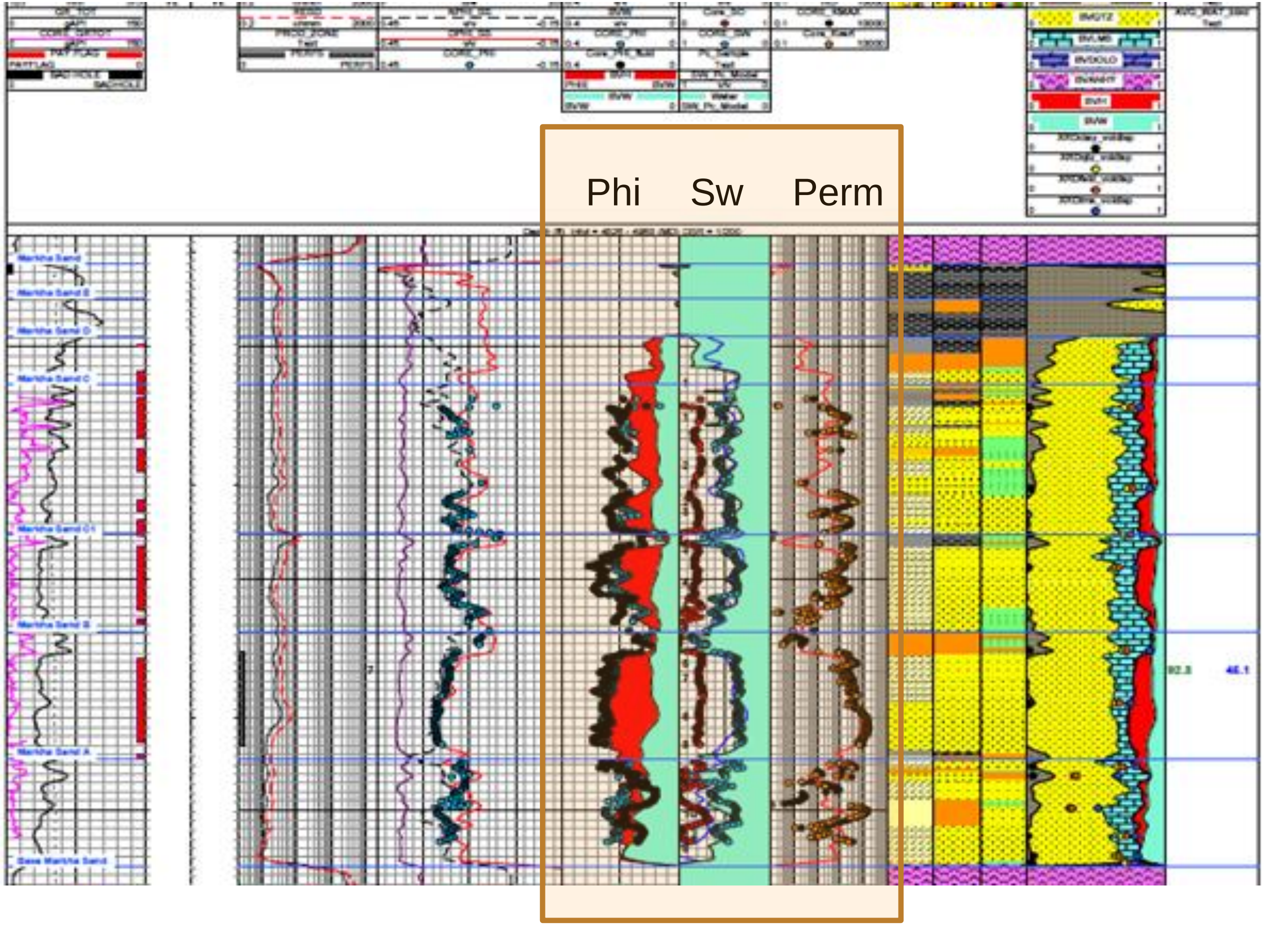
- Gas Perm.
- Klikenberg Perm.

Dean-Stark Water Saturation

Routine Core Analysis Data (RCA)

Core no.	Sample no.	Depth (m)	Kg, hor. (mD)	1/Pm, hor.	Kl, hor (mD)	Kg, vert. (mD)	1/Pm, vert.	Kl, vert. (mD)	Por., hor. (%)	Por., vert. (%)	Por. sum. (%)	So (%)	Sw (%)	Gr.dens. hor. (g/cc)	Gr.dens. vert. (g/cc)	Lithological description
1	1	3837	13.8	0.662	11.5				17					2.66		Sst.lt-Brn.M-gr.Ang.W-cmt.Fr-srt.mtrx.frac.w/Mic,Pyr,Calc,C,
1	2	3837.25	NMP		NMP				14.8					2.67		A.A.fis.Cl/Mic-lam.w/o frac.w/Dol,Sid,Cl.
1	3	3837.55	25.2	0.746	21.4	3.94	0.495	3.16	10.8					2.69		A.A.VW-cmt.w/o fis.Cl/Mic-lam.incr Dol.
1	4	3837.8	1.02	0.495	0.694				12.8					2.7		A.A.F/M-gr.frac.Slty.incr Pyr.
1	5	3837.88								18.8		52.9	36.4		2.68	
1	6	3838	524	0.976	491				16.4					2.69		A.A.Sb-ang.Fr-cmt.P-srt.fis.w/o frac,Slty.decr Dol
1	7	3838.25	274	0.968	253				16.5					2.66		A.A.W-cmt.Fr-srt.w/o fis.decr Pyr.
1	8	3838.5	1130	0.992	1080	1100	0.989	1040	17.2					2.66		A.A.M-gr.
1	9	3838.75	442	0.978	412				16.9					2.66		A.A.F/M-gr.
1	10	3838.92								19.5		72.5	11		2.68	
1	11	3839	19.3	0.693	16.3				20.1					2.66		A.A.styl.
1	12	3839.2	0.298	0.495	0.189				10.3					2.93		A.A.Pyr-sst.C-lam.w/o styl.
1	13	3839.4	6.54	0.54	5.36	1200	0.99	1140	12.7					3.03		A.A.w/o C-lam.
1	14	3839.75	593	0.984	557				19					2.66		A.A.Sst.M-gr.
1	15	3839.92								8.6		23.9	52.4		2.74	
1	16	3840	0.151	0.495	0.092				9.9					2.91		Sst.Gry.F-gr.Sb-ang.VW-cmt.W-srt.Mtrx.w/Pyr.ltl-Cl,Mic.
1	17	3840.2	260	0.969	238				20.6					2.63		A.A.lt-Brn.F/M-gr.styl.
1	18	3840.45	168	0.936	152	17.6	0.693	14.8	21					2.66		A.A.
1	19	3840.75	317	0.971	293				22.7					2.64		A.A.
1	20	3840.94								24.4		61.6	21.7		2.64	
1	21	3841	44.8	0.808	38.9				21.9					2.69		A.A.Crs-gr.VP-srt.incr Pyr,C.
1	22	3841.2	207	0.969	189				20					2.63		A.A.M-gr.Fr-srt.decr Pyr.
1	23	3841.45	65	0.88	57	19.4	0.693	16.4	22.1					2.62		A.A.F/M-gr.decr C.
1	24	3841.75	50.4	0.855	43.7				17.7					2.63		A.A.slty.Styl.
1	25	3841.93								13.9		31.7	43.4		2.63	

Well Log Interpretation Validation



Q & A

Session 1 – Break

What Information that you can obtained from Core?

Slabbed Core

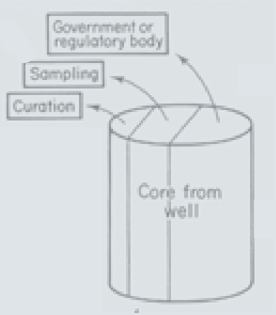
- ✓ Photograph
- ✓ Sedimentology
- ✓ Lithology
- ✓ Stratigraphy

Thin Section

- ✓ Detail Pore Structure
- ✓ Diagenesis
- ✓ Porosity Type
- ✓ Environmental evidence

Small Sample

- ✓ Grain Size Distribution
- ✓ Mineral analysis
- ✓ X-ray and SEM analysis
- ✓ Bio-dating and association



Calibration of Log Interpretation

Routine Core Analysis

- ✓ Porosity
- ✓ Permeability
- ✓ Grain Density
- ✓ As-received saturation

Special Core Analysis

- ✓ Capillary Pressure
- ✓ Relative Permeability
- ✓ Electrical Properties
- ✓ Acoustic Properties
- ✓ Compressive Properties
- ✓ Clay chemistry effects

Advance Core Analysis

- ✓ NMR
- ✓ Digital Rock Physics
- ✓ Rock Mechanics
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SPECIAL CORE ANALYSIS

Coring Process

Cleaning and Drying

Electrical measurement

- Formation Factor (a & m)
- Resistivity index (n)

Capillary Pressure

- Porous Plate
- Centrifuge
- MICP

Wettability

- Amott
- USBM

Relative Permeability

- Gas-Oil
- Gas-Brine
- Water-Oil

Acoustic measurement

- P & S Waves Velocity
- P & S Waves Attenuation

Compressive Properties

- Poisson Ratio
- Young Modulus
- Brittleness Index

Clay Chemistry Effect

- Cation Exchange Capacity (CEC)
- Swelling Test

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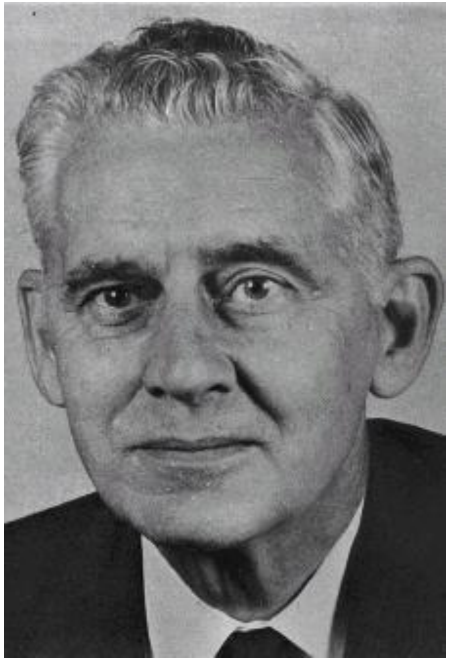
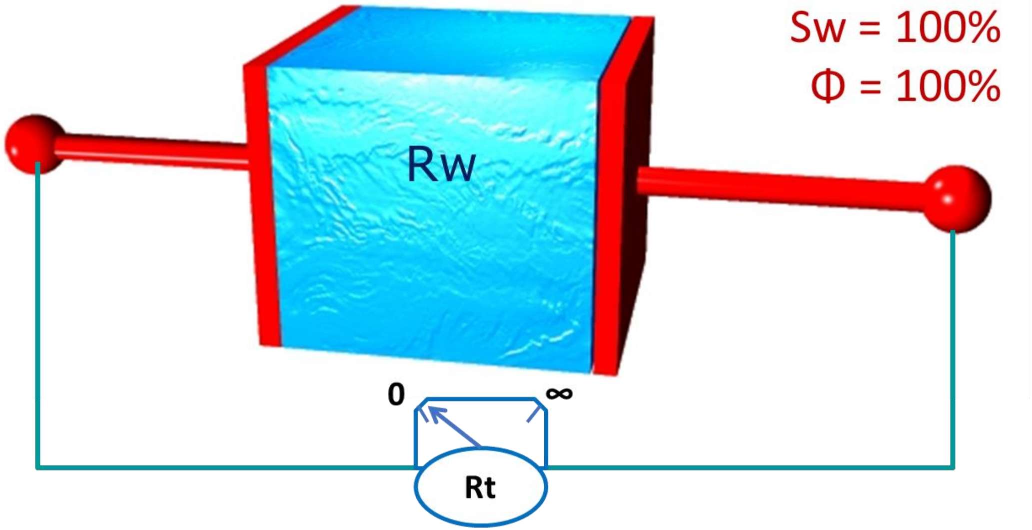
Electrical Measurement



Gus Archie (ca.1942)

$$S_W = \sqrt[n]{\frac{a \, . \, R_W}{\phi^m . \, R_t}}$$

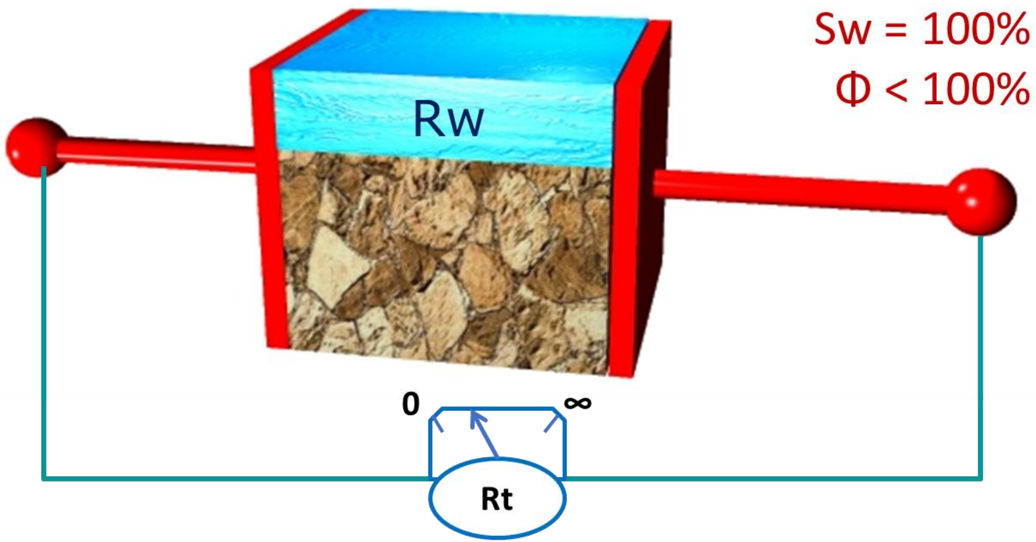
Electrical Measurement



Rt = Rw

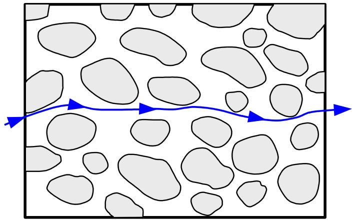
Electrical Measurement

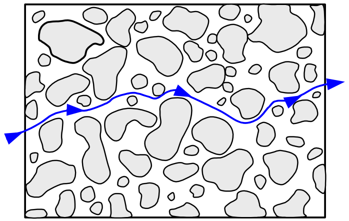
R_0 ?

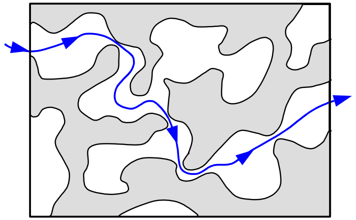


Ro = Rt > Rw

Formation Factor (FF)





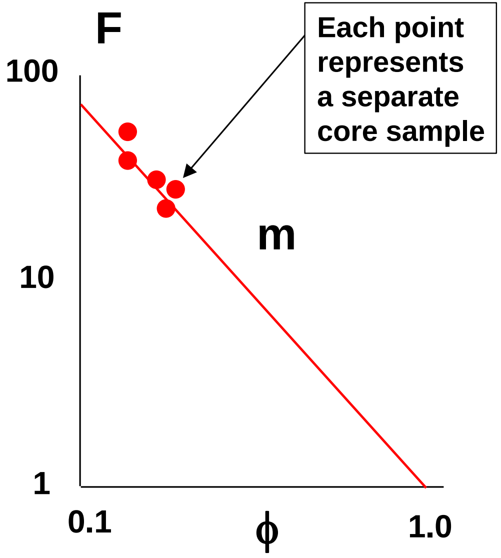


First Law

$$R_0 = F \cdot R_w \qquad R_0 = \frac{R_w}{\phi^m} \qquad F = \frac{1}{\phi^m}$$

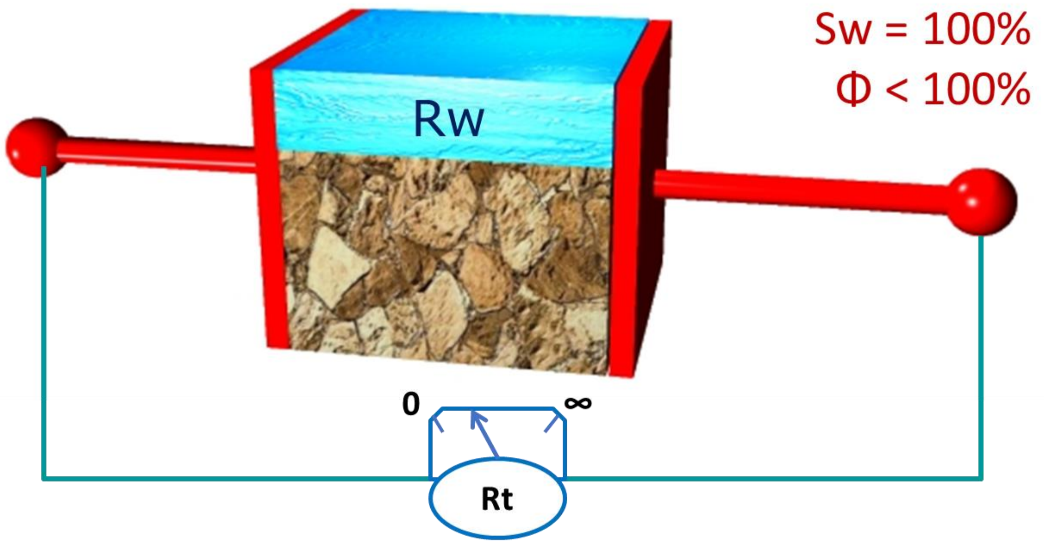
$$F = R_o / R_w = \phi^{-m}$$

F	=	Formation resistivity factor (FRF)
R_o	=	Resistivity of 100 % brine saturated rock
R_w	=	Brine resistivity (Ωm)
ϕ	=	Porosity
m	=	Cementation factor



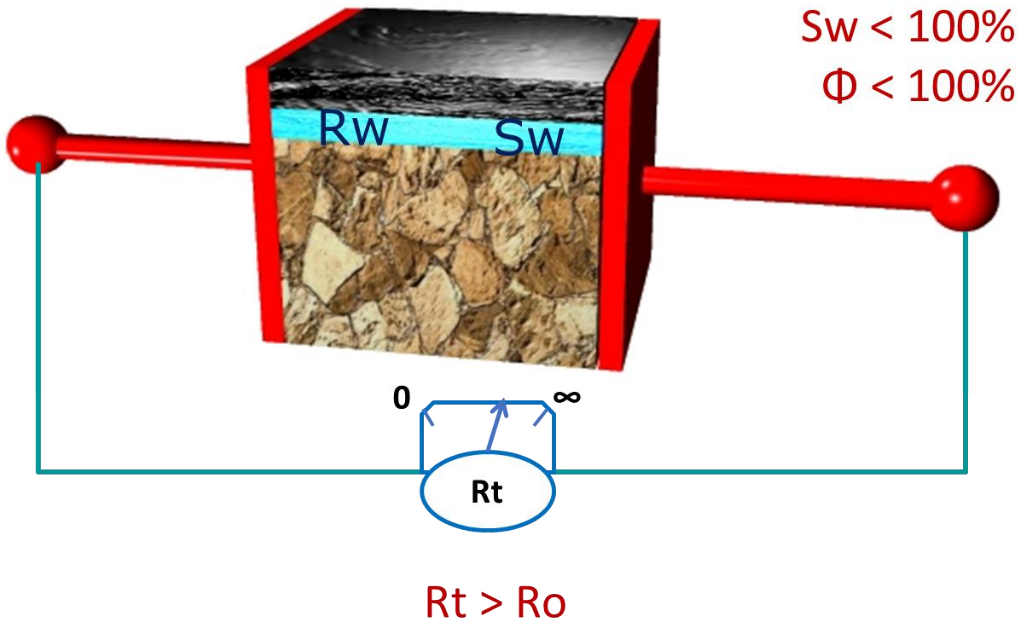
Electrical Measurement

R_0 ?



Ro = Rt > Rw

Electrical Measurement



Resistivity Index (RI)

Second Law

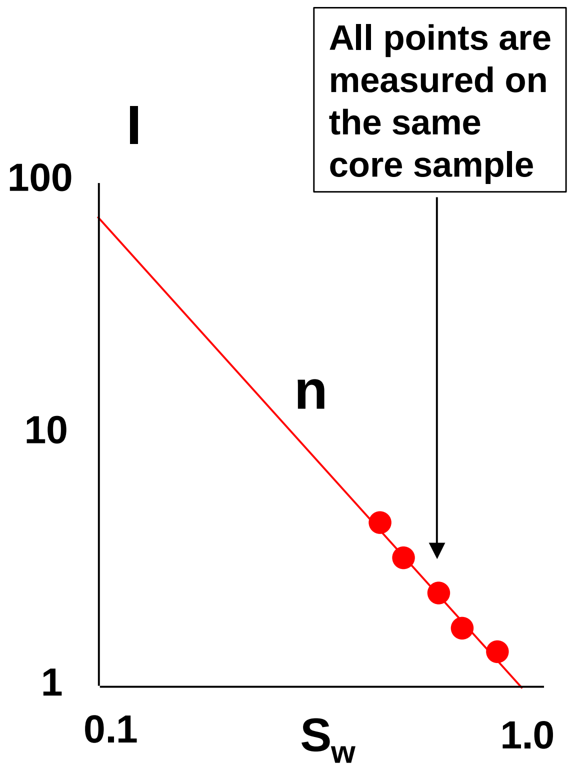
$$R_t = I \cdot R_0$$

$$I = R_t / R_o = S_w^{-n}$$

$$R_t = \frac{R_0}{{S_w}^n}$$

I = Resistivity index
R_t = Resistivity of partly brine saturated rock
R_o = Resistivity of fully brine saturated rock
S_w = Water saturation
n = Saturation exponent

$$I = \frac{1}{{S_w}^n}$$



Understanding - Archie

I. $$R_0 = \frac{R_w}{\phi^m}$$

II. $$R_t = \frac{R_0}{S_w^{\,n}}$$

$$R_t = \frac{a \cdot R_w}{\phi^m \cdot S_w^{\,n}}$$

$$S_W = \sqrt[n]{\frac{a \,.\, R_W}{\phi^m . R_t}}$$

Understanding - Archie

Saturation exponent "n"

- Struktur & Geometri Pori
- Wettability — Morgan & Pirson (1964), Andersen (1986)
- Salinity
- Rw
- Temperature

a is not a tourtousity!

a Archie's = 1

$$R_t = \frac{a \cdot R_w}{\emptyset^m \cdot S_w^{\,n}}$$

m is not a cementation factor!

Called as Porosity exponent

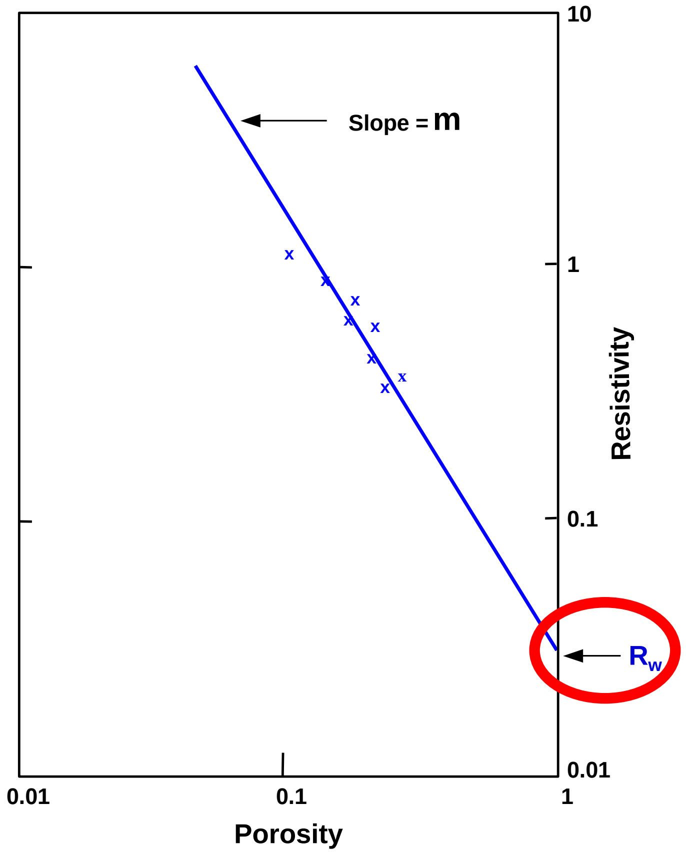
"m" — Depend on

- Rock Packing (Archie,1942)
- Struktur & Geometri Pori (Aguilera, 1976)
- Permeability (Raiga Clemencau, 1977)
- Grain shape (Atkins & Smith, 1961)
- Pressure (Glanvile, 1959)
- Salinity (Core data)

In-Situ Rw Estimations

$$R_0 = \frac{R_w}{\varnothing^m}$$

$$\log R_0 = \log R_w - m \cdot \log \varnothing$$

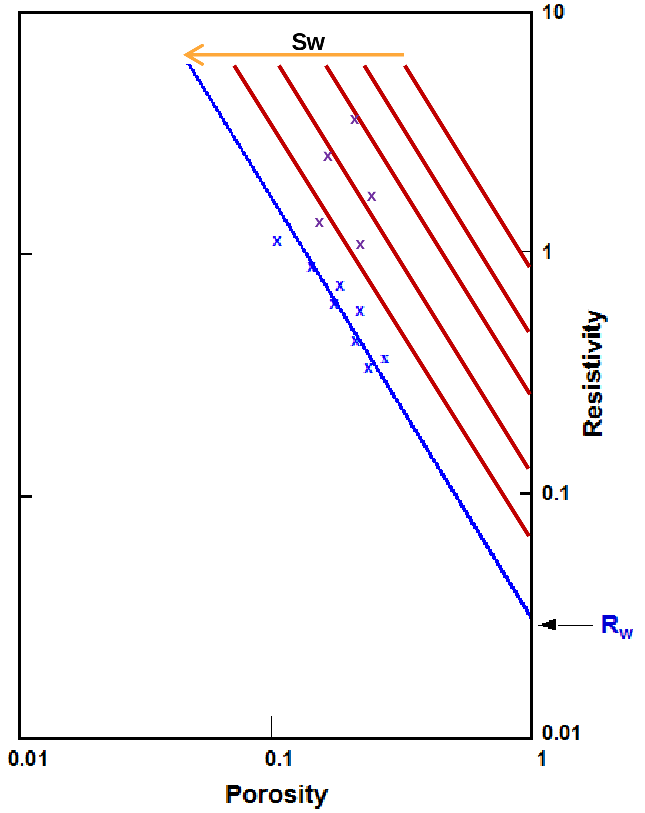


In-Situ Rw Estimations

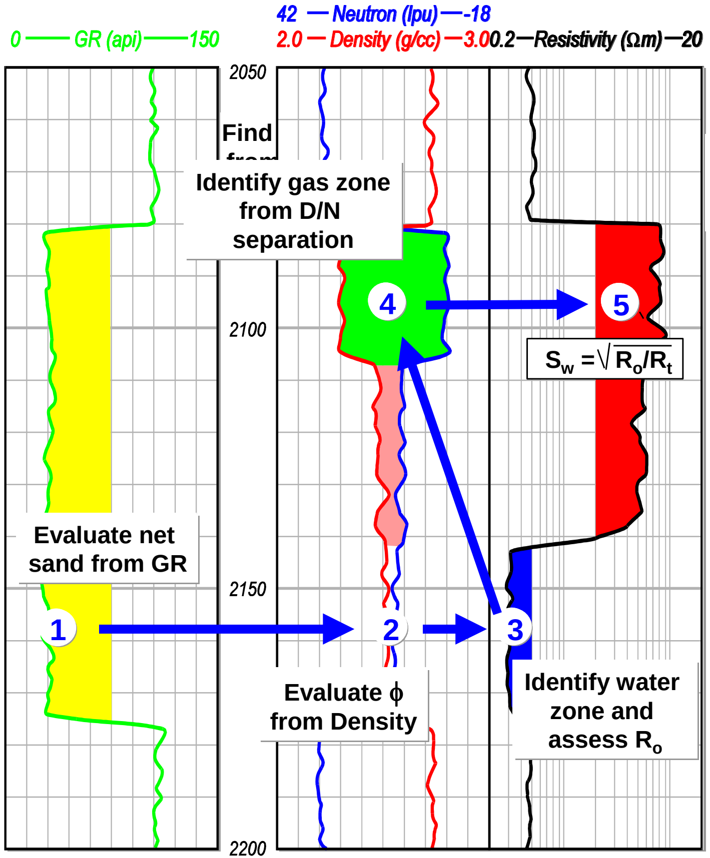
- Pickett-plot

$$R_t = \frac{R_w}{\emptyset^m {S_w}^n}$$

$$\log R_t = log\, R_w - m \cdot log\, \emptyset - n \cdot log\, S_w$$



Quick-Look in Nutshell



$$R_0 = \frac{R_w}{\phi^2}$$

$$S_w = \sqrt{\frac{R_w}{\phi^2 \cdot R_t}}$$

$$S_w = \sqrt{\frac{R_0}{R_t}}$$

SPECIAL CORE ANALYSIS

Coring Process

Cleaning and Drying

Electrical measurement
- Formation Factor (a & m)
- Resistivity index (n)

Capillary Pressure
- Porous Plate
- Centrifuge
- MICP

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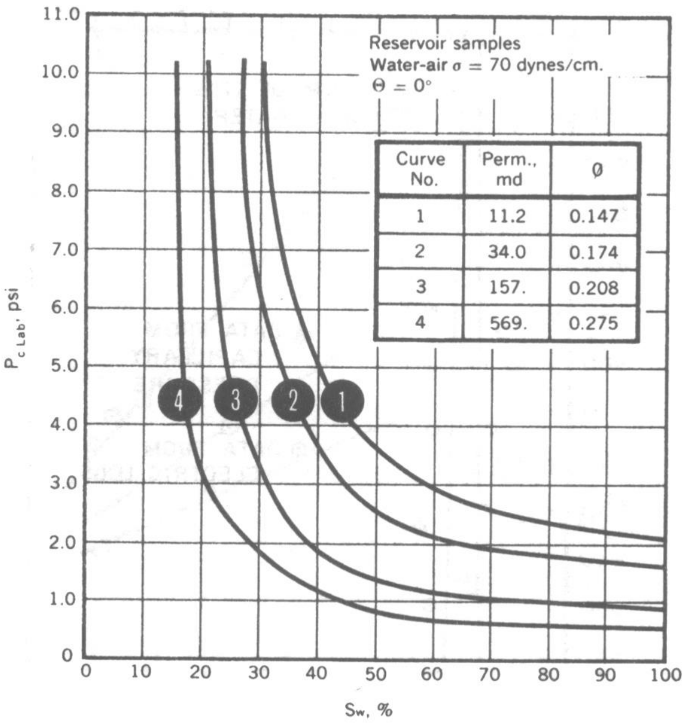
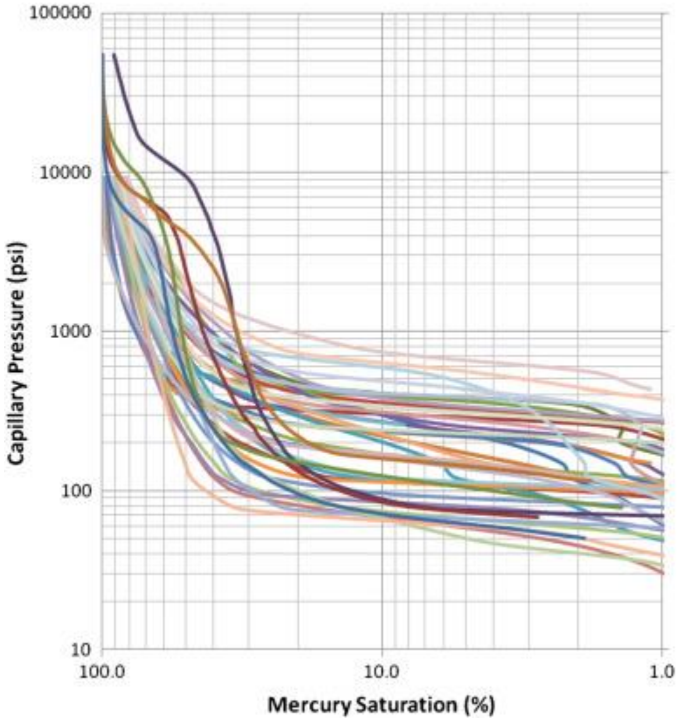
- P & S Waves Velocity
- P & S Waves Attenuation

Compressive Properties
- Poisson Ratio
- Young Modulus
- Brittleness Index

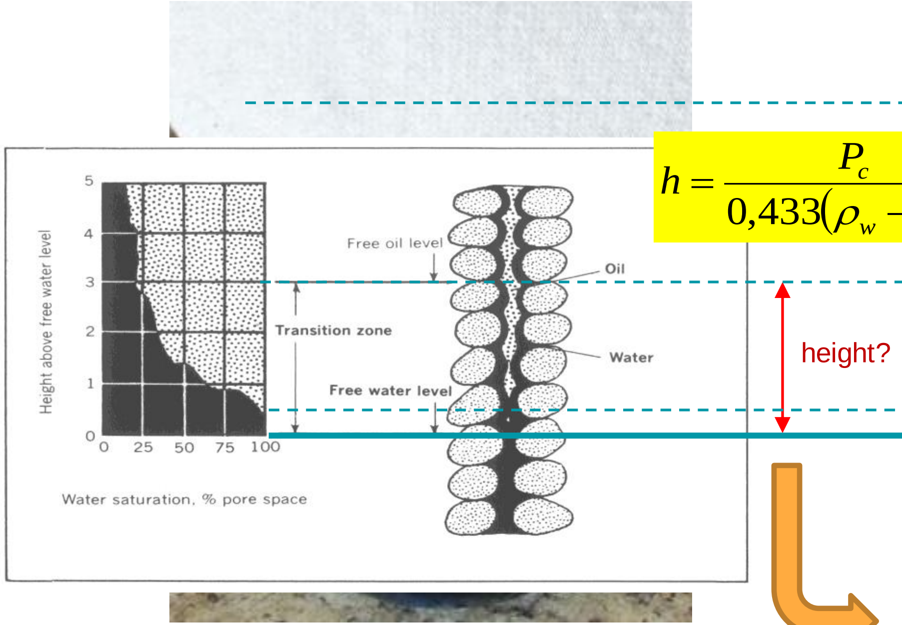
Clay Chemistry Effect
- Cation Exchange Capacity (CEC)
- Swelling Test

Capillary Pressure Data

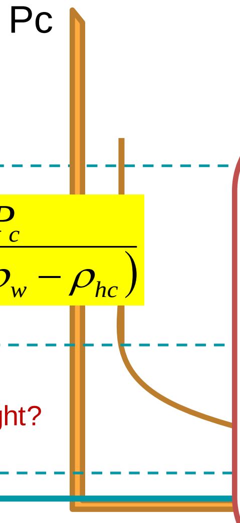




SCAL - Capillary Pressure Concept



$$h = \frac{P_c}{0{,}433(\rho_w - \rho_{hc})}$$



Combining Eqs. (1), (2), and (3) results in the equation below:

$$H = \frac{[constant_1 \times \sigma cos\theta \times (S_W)^{-b}]}{\left[(\rho_W - \rho_O)\left(\sqrt{k/\emptyset}\right)\right]}$$

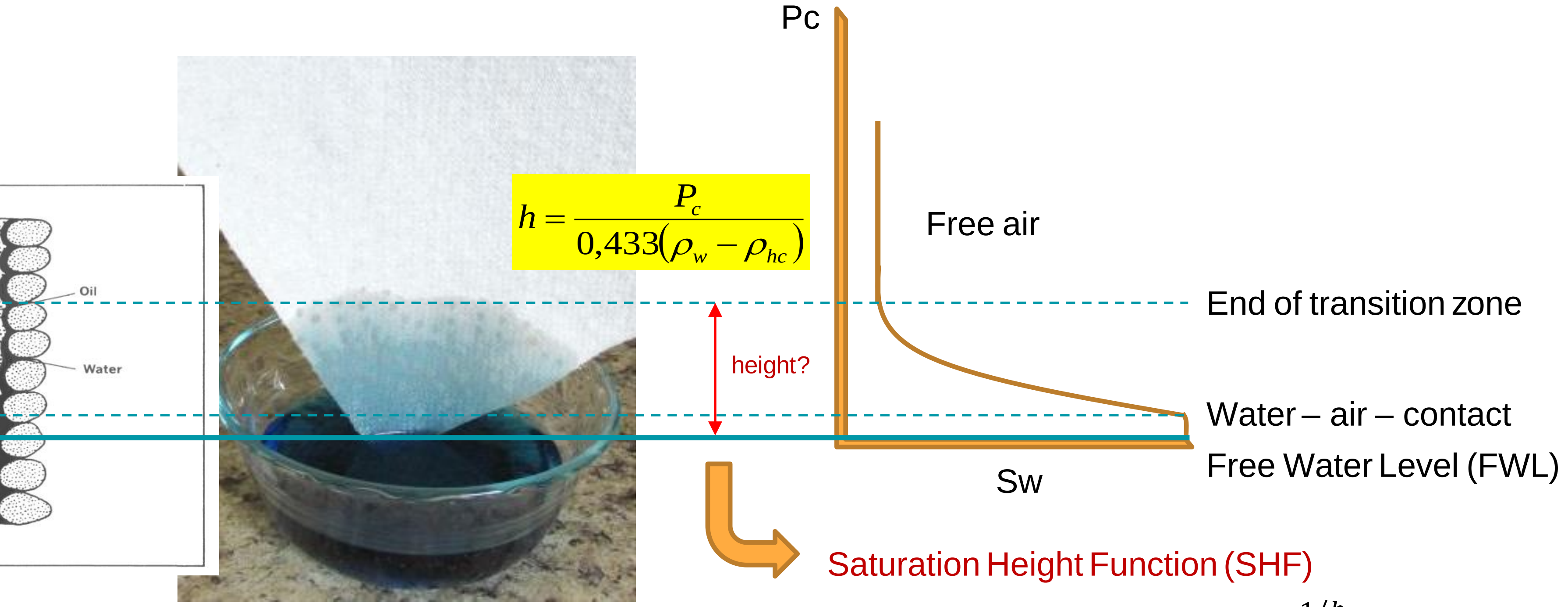
or

$$S_W = \left[\frac{constant_2 \times H(\rho_W - \rho_O)\left(\sqrt{k/\emptyset}\right)}{\sigma cos\theta}\right]^{-1/b}$$

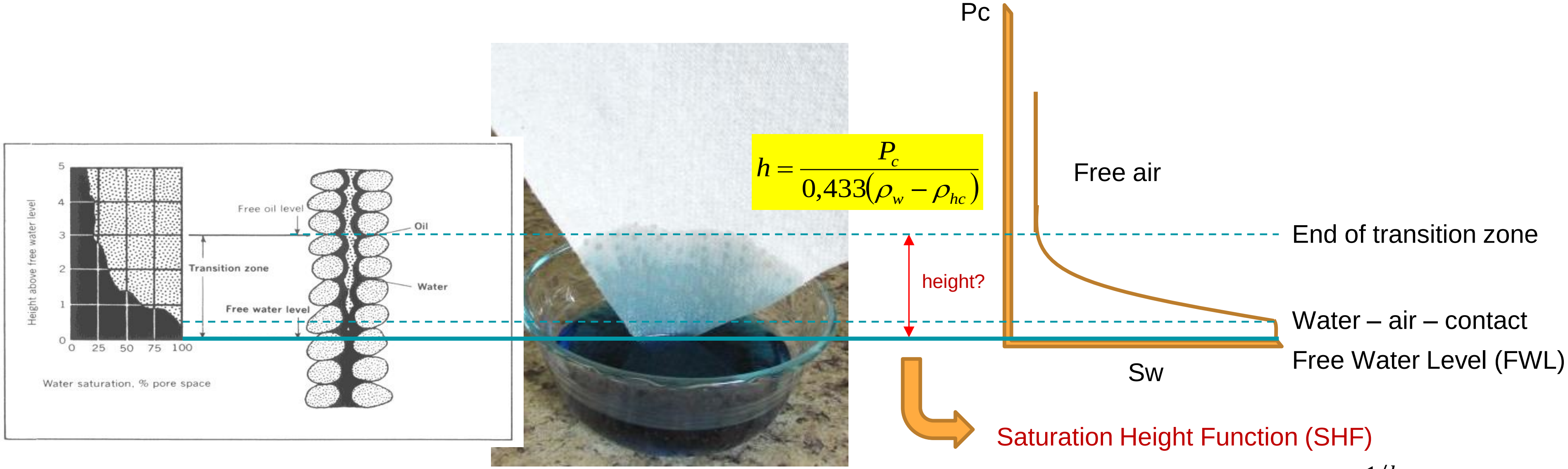
Each rock type has its own equations for *H* and S_w

Saturation Height Function (SHF)

SCAL - Capillary Pressure Concept



$$S_w = \left[\frac{constant_2 \times H(\rho_W - \rho_O)\left(\sqrt{k/\emptyset}\right)}{\sigma cos\theta}\right]^{-1/b}$$

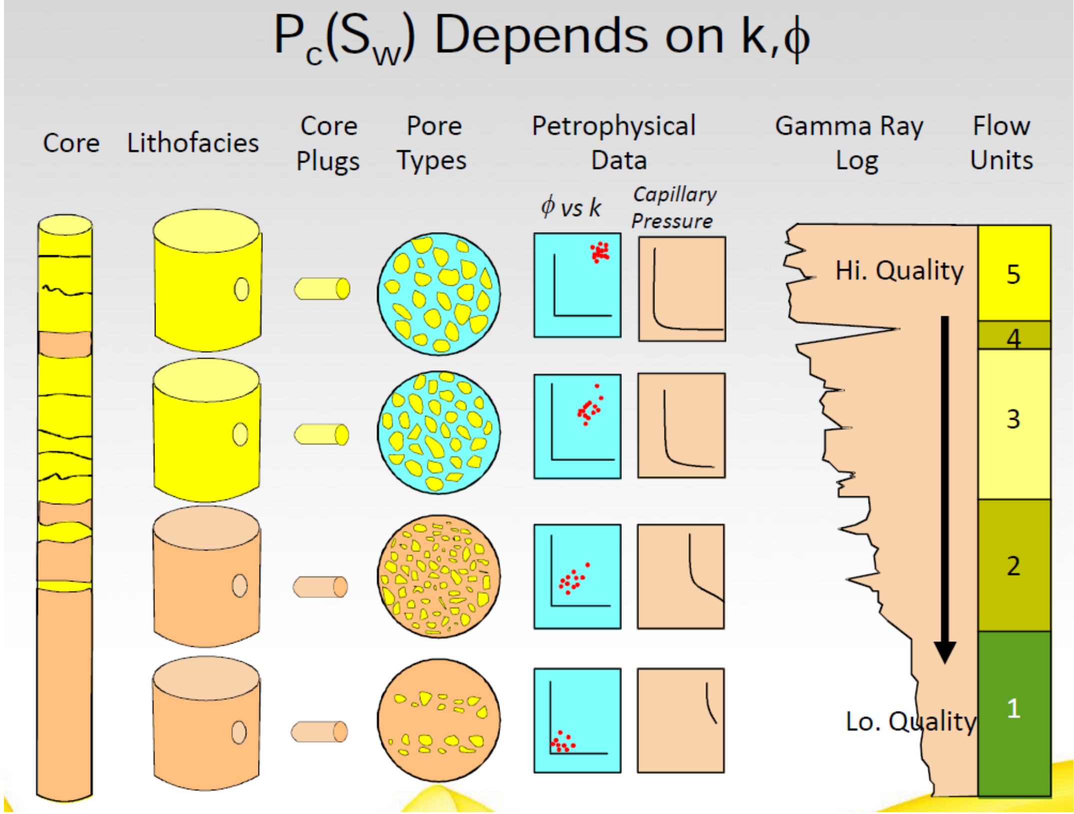


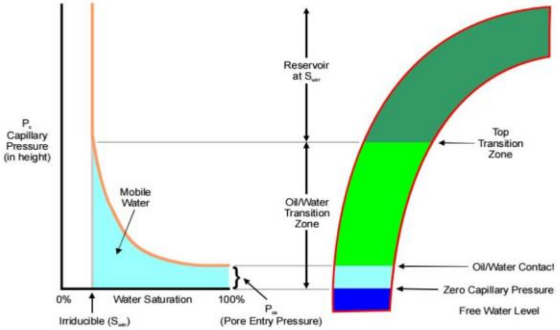
$$h = \frac{P_c}{0{,}433(\rho_w - \rho_{hc})}$$

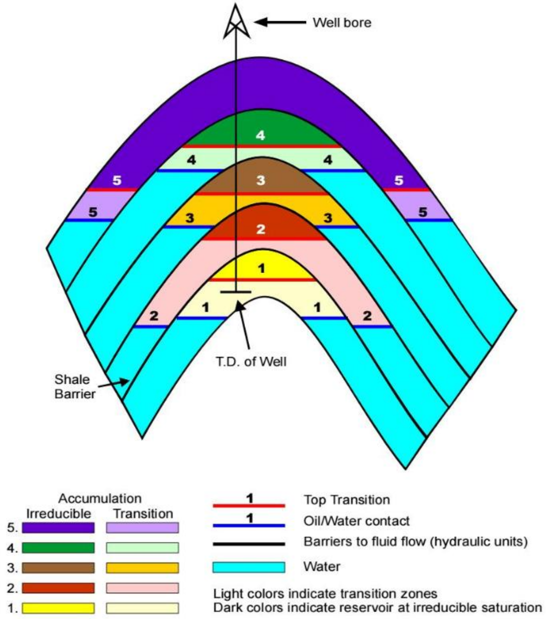
Saturation Height Function (SHF)

$$S_w = \left[\frac{constant\_ \times H(\rho_W - \rho_O)\left(\sqrt{k/\emptyset}\right)}{\sigma cos\theta}\right]^{-1/b}$$

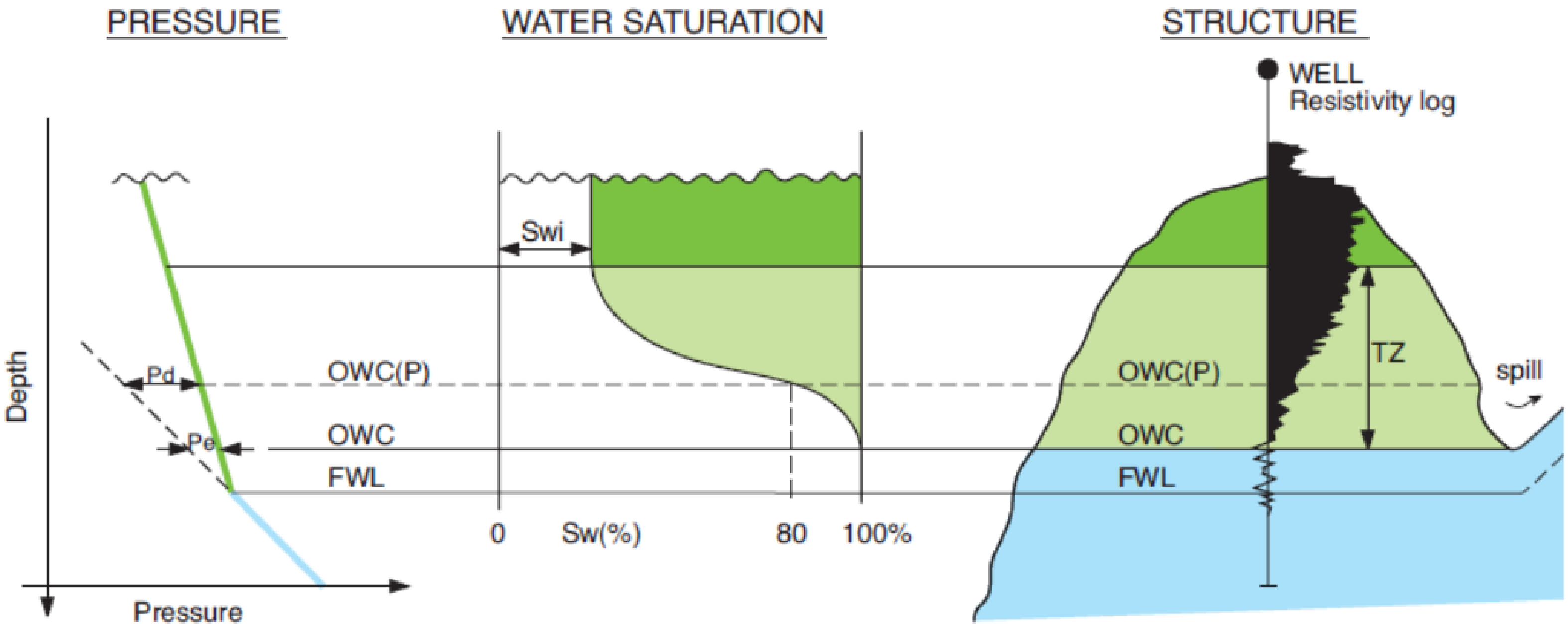
SCAL - Capillary Pressure Application







SCAL - Capillary Pressure Application



FWL = Free water level

OWC = Oil water contact

OWC(P) = Productive oil water contact

Sw = water saturation

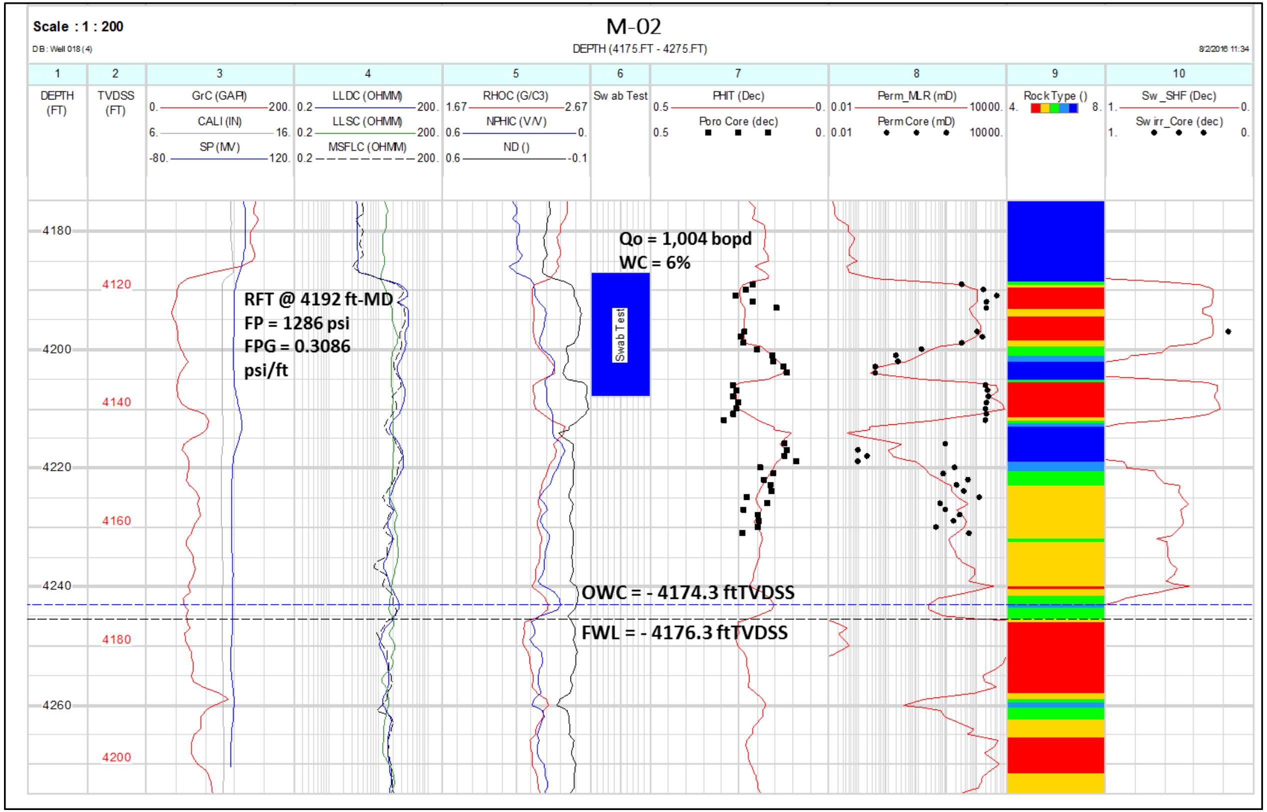
Swi = irreducible water saturation

TZ = Transition zone

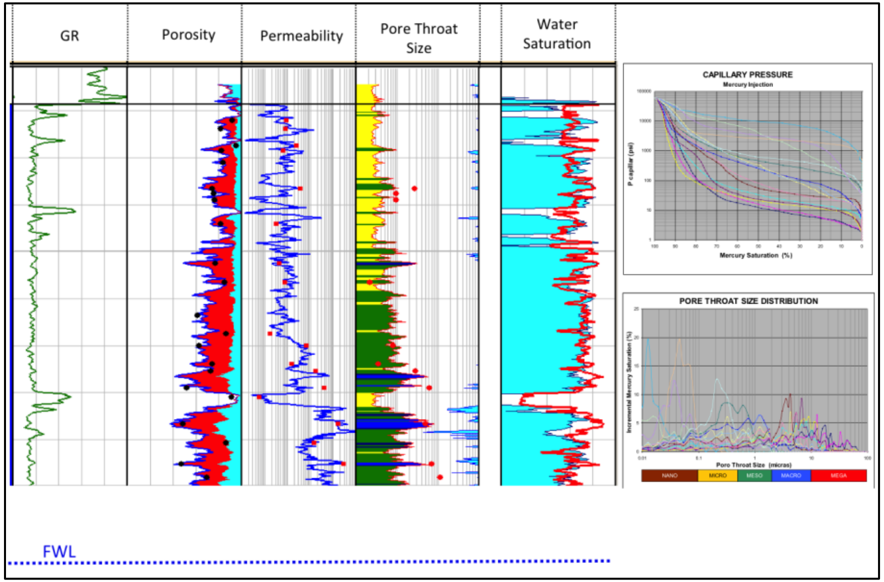
Pe = Capillary entry pressure - oil begins to invade pore spaces

Pd = Capillary displacement pressure - oil invades connected pore spaces (usually approximates to the OWC(P)

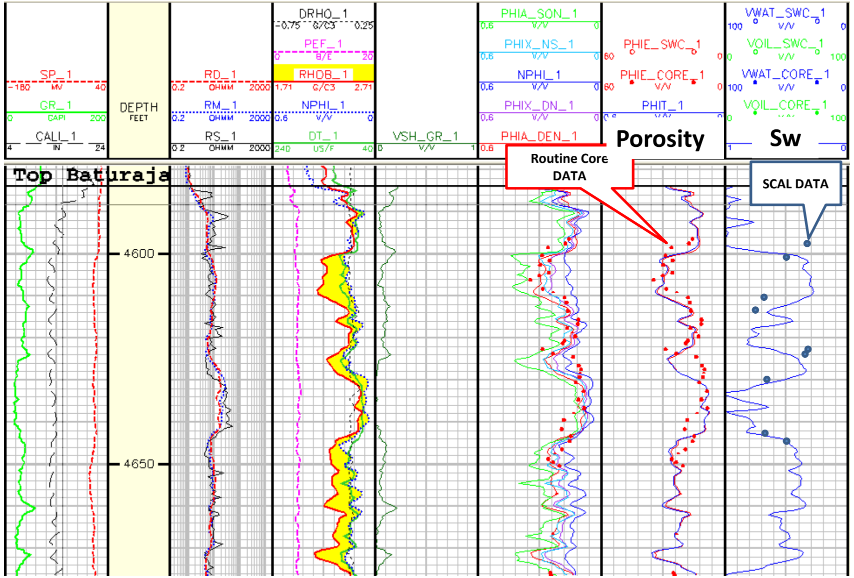
Case study of SHF



Case study



Kalibrasi: Log Interpretation vs Core Data



SPECIAL CORE ANALYSIS

Coring Process

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- Formation Factor (a & m)
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Capillary Pressure

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Compressive Properties

- Poisson Ratio
- Young Modulus
- Brittleness Index

Clay Chemistry Effect

- Cation Exchange Capacity (CEC)
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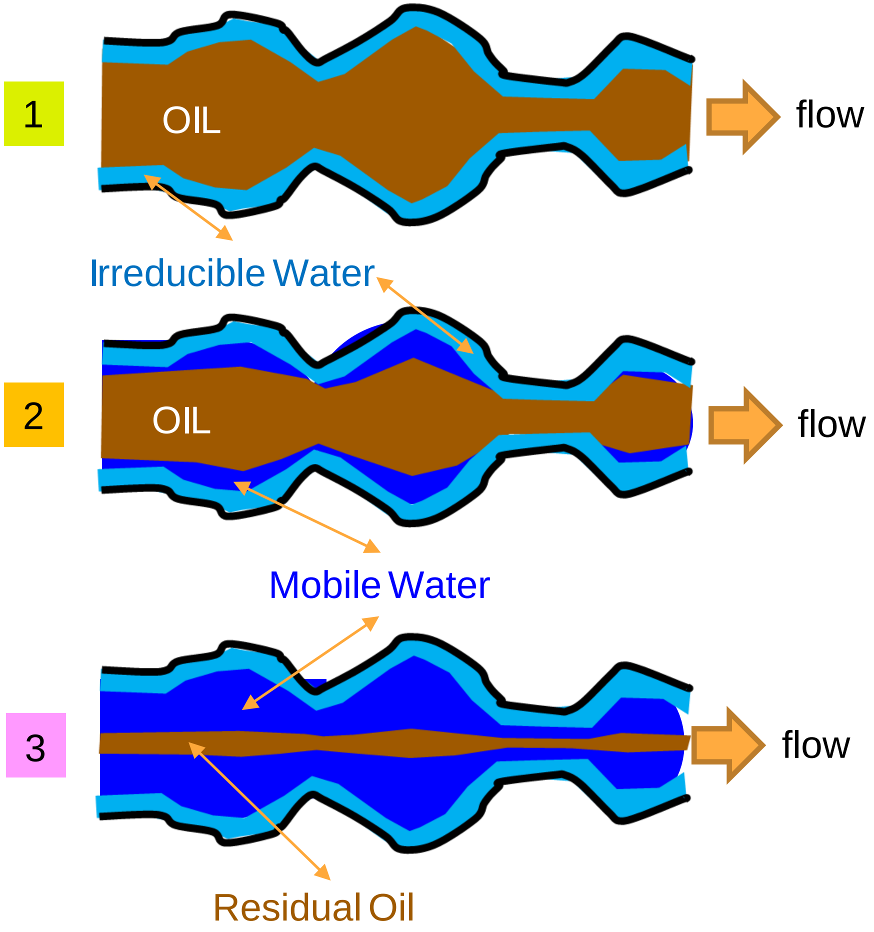
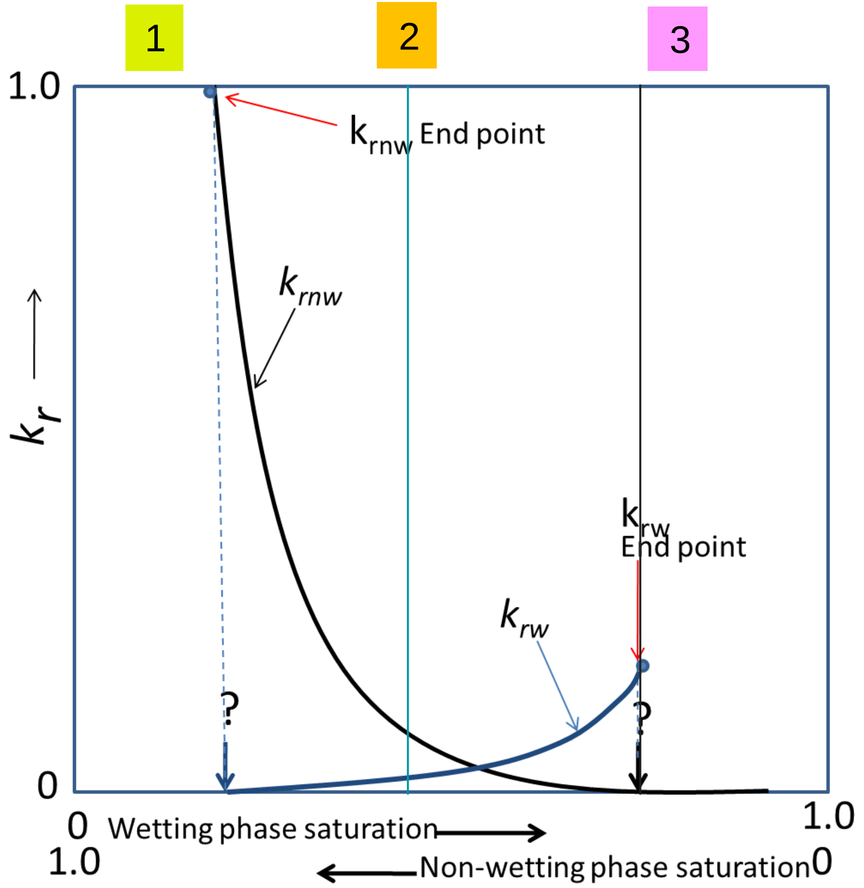
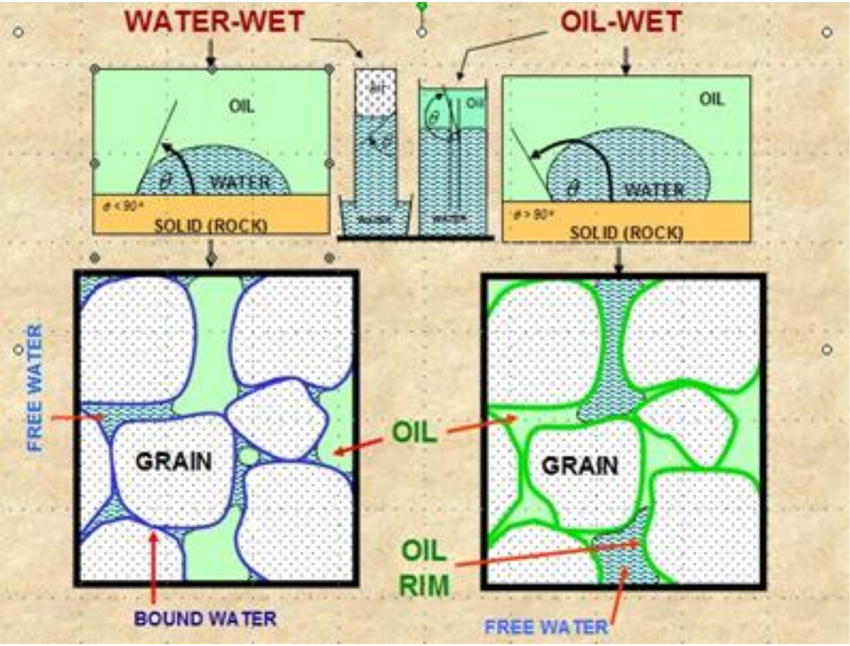
RELATIVE PERMEABILITY CONCEPT



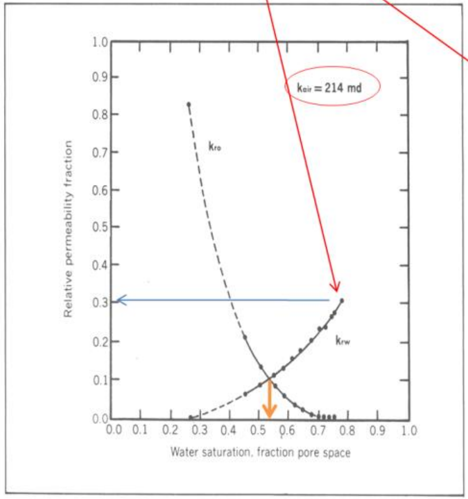


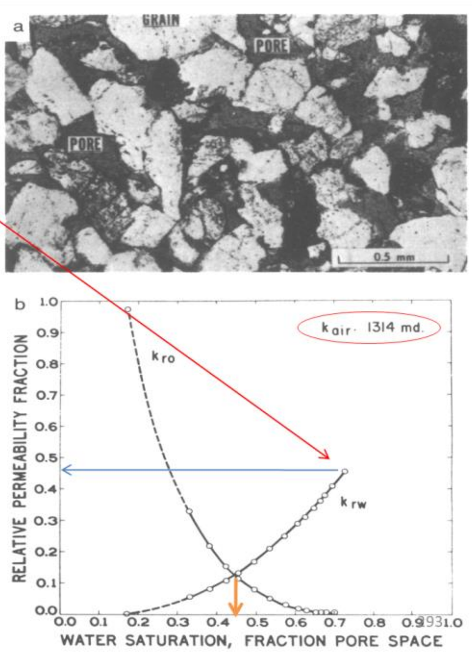
Wettability and Relative Permeability

Pengaruh permeabilitas absolut terhadap kurva k_r



Perhatikan ***end point*** pada kedua gambar sebelah kiri dan kanan.





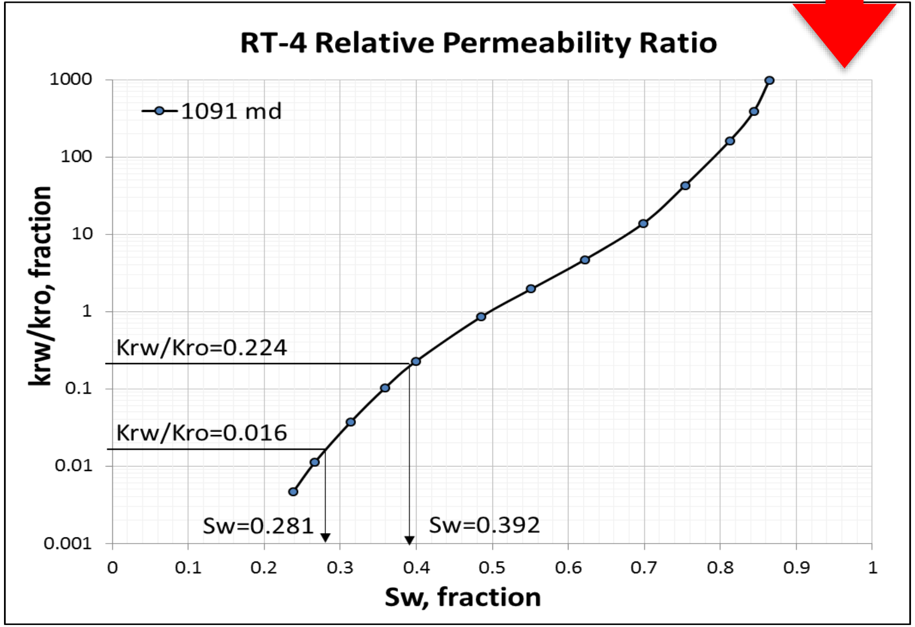
Application in Transition Zone

$$\frac{k_{rw}}{k_{ro}} = \frac{\mu_w}{\mu_o}\frac{B_w}{B_o}\left(\frac{WC}{1-WC}\right)$$

By using this Equation, based on flow test data

M-01, WC = 47% ➔ k_{rw}/k_{ro} = 0.224

M-02, WC = 6% ➔ k_{rw}/k_{ro} = 0.016



- Determine the distance vertically down from **the midpoint of the dominant rock type**.
- **RT -4** is the best rock type and expected to dominantly contribute to the fluids flow within the tested interval.
- **OWC** was determined by this equation when Sw = 100%

$$H = \frac{0.356 \times Sw^{-3.53}\ \sigma\cos\theta}{(\rho_w - \rho_o)\sqrt{\frac{k}{\emptyset}}}$$ → **Above FWL**

<u>(M-02) Well</u>

$$H = \frac{0.356 \times 0.281^{-3.53}\ 30\cos(30)}{(1.021 - 0.757)\sqrt{\frac{1069}{0.238}}}$$

= <u>47.80</u> *ft*

→ *k* & ϕ was Taken from **4128.5 ft** TVDSS M-02

<u>(M-01) Well</u>

$$H = \frac{0.356 \times 0.392^{-3.53}\ 30\cos(30)}{(1.021 - 0.757)\sqrt{\frac{557}{0.263}}}$$

= <u>21.49</u> *ft* **(M-01)**

→ *k* & ϕ was Taken from **4156 ft** TVDSS M-01

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Clay Chemistry Effect

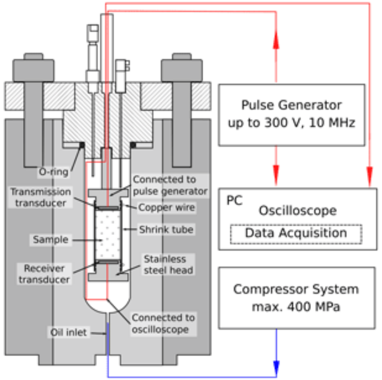
- Cation Exchange Capacity (CEC)
- Swelling Test

P-WAVE VELOCITY

Vp

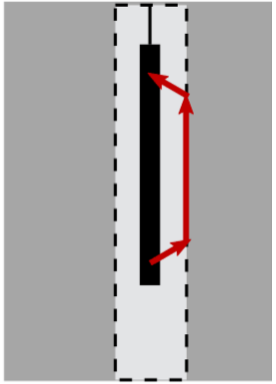
Core ⟷ Well ⟷ Seismic

Scale: 10^{-1} m



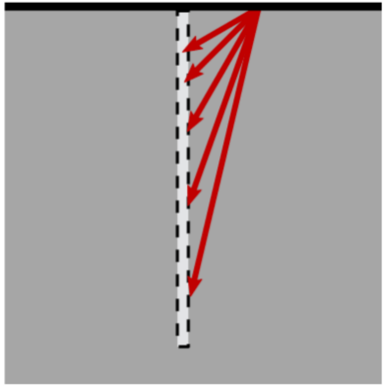
Core Vp

Scale: 1 m



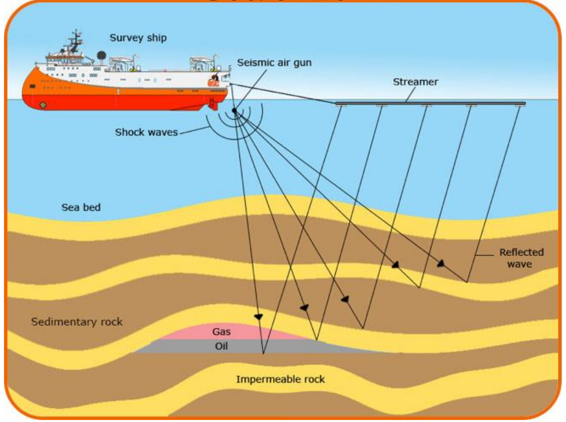
Sonic Log

Scale: 10 m



VSP/Checkshot

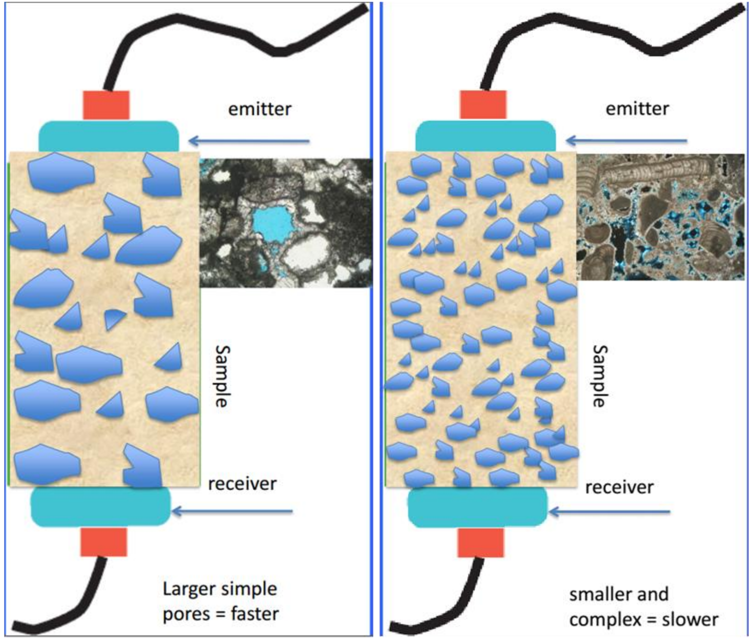
Scale: 10^3 m



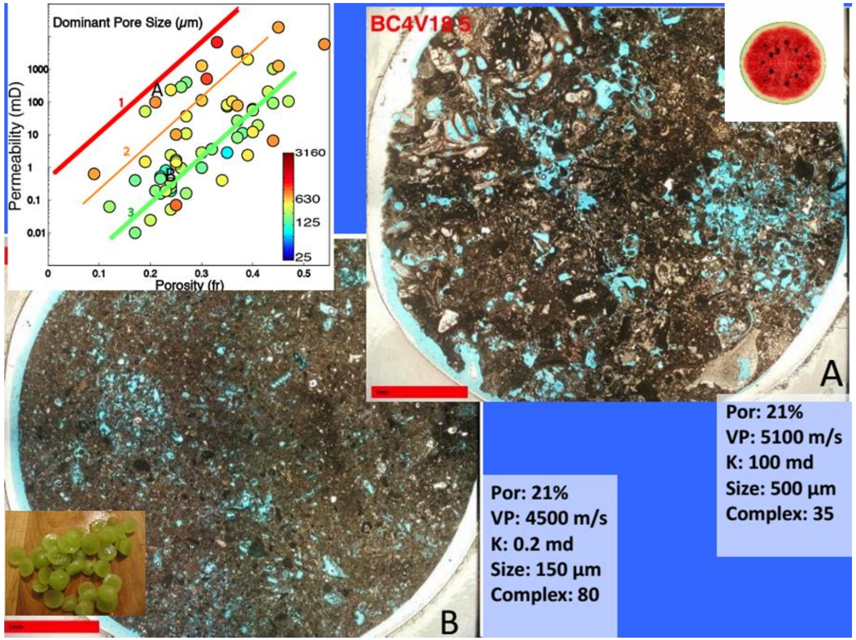
Experiment done

-- All work in different resolution --

Vp Measurement in Carbonate



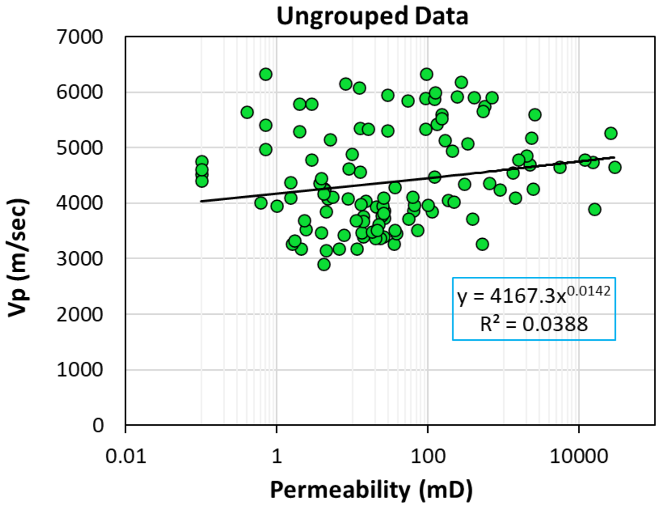
After Weger and Eberli, 2009



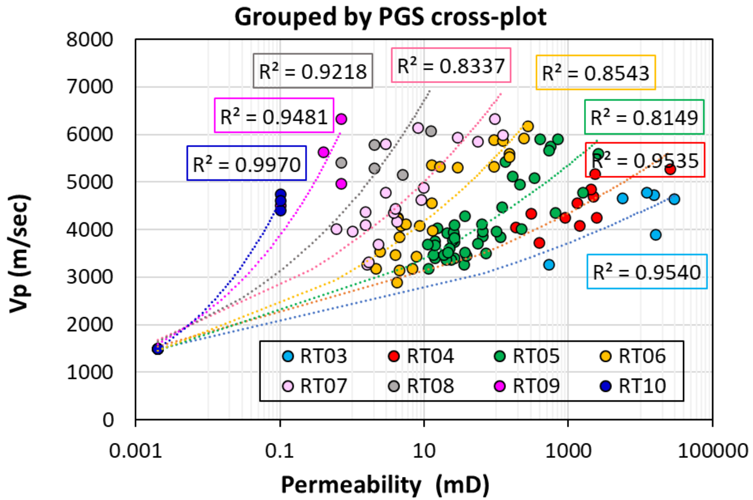
Correlating Vp vs. Permeability

CARBONATE

Correlation among P-wave velocity and Permeability is too weak

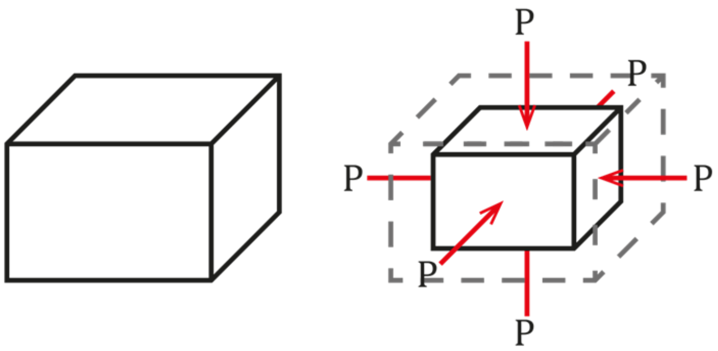


Very good correlations when the rock samples are grouped based on PGS

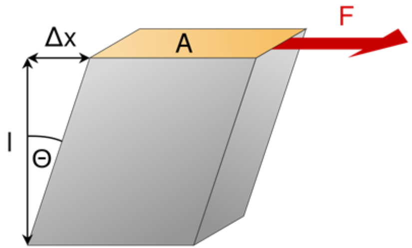


***V_p* increases** with **Permeability** in each Rock Type

Elastic Properties

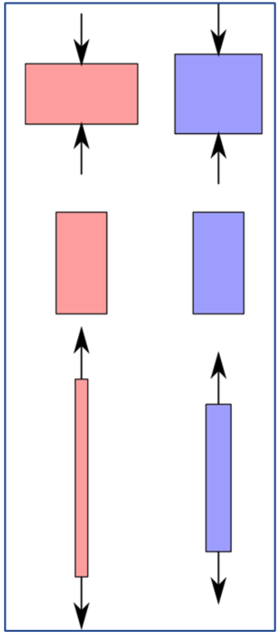


Bulk modulus (*B*) is a measure of material resistance to change in volume. The parameter *B* is inversely proportional to compressibility, the higher the bulk modulus, the less compressible the material is.



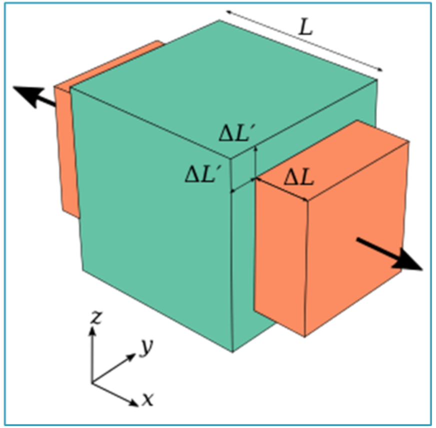
Shear Modulus or also known as modulus of rigidity is a measure of material resistance to change in shape due to solid-fluid interaction.

Elastic Properties



Young Modulus (*E*) or stiffness of the rocks are measured by the ratio of the uniaxial stress against the resultant strain of the sample

Poisson's ratio is a measure of the Poisson effect, the phenomenon in which a material tends to expand in directions perpendicular to the direction of compression.



Application

Young's modulus

$$E = \frac{\rho V_s^2(3V_p^2 - 4V_s^2)}{V_p^2 - V_s^2}$$

Poisson's ratio

$$v = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)}$$

Normalization

$$E_{brittle} = \frac{E - E_{min}}{E_{max} - E_{min}}$$

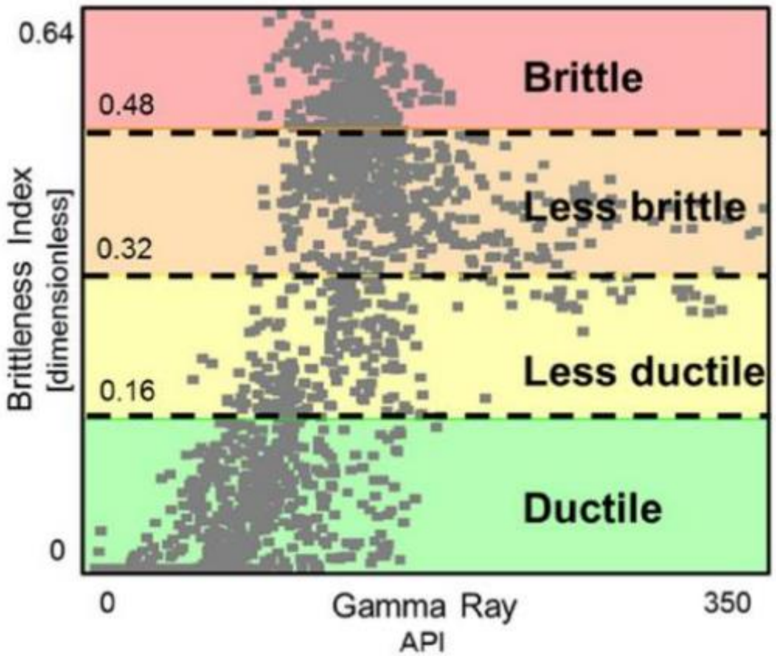
$$v_{brittle} = \frac{v - v_{min}}{v_{max} - v_{min}}$$

Brittleness Index

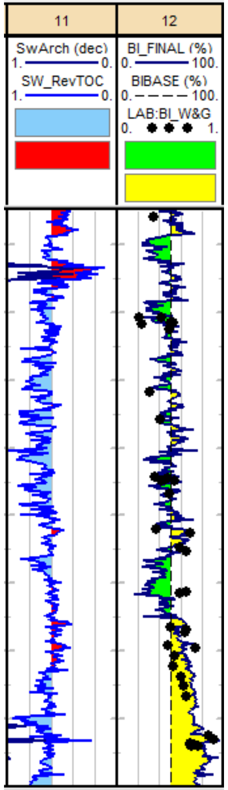
$$BI_{sonic} = \frac{E_{brittle} + v_{brittle}}{2} \times 100\%$$

Then, it is compared to calculated BI from rock composition

$$BI_{W\&G} = \frac{Q_z + Dol}{Qz + Cal + TOC + Cly + Dol}$$



Brittleness index classification (Perez, 2014)



What Information that you can obtained from Core?

Slabbed Core

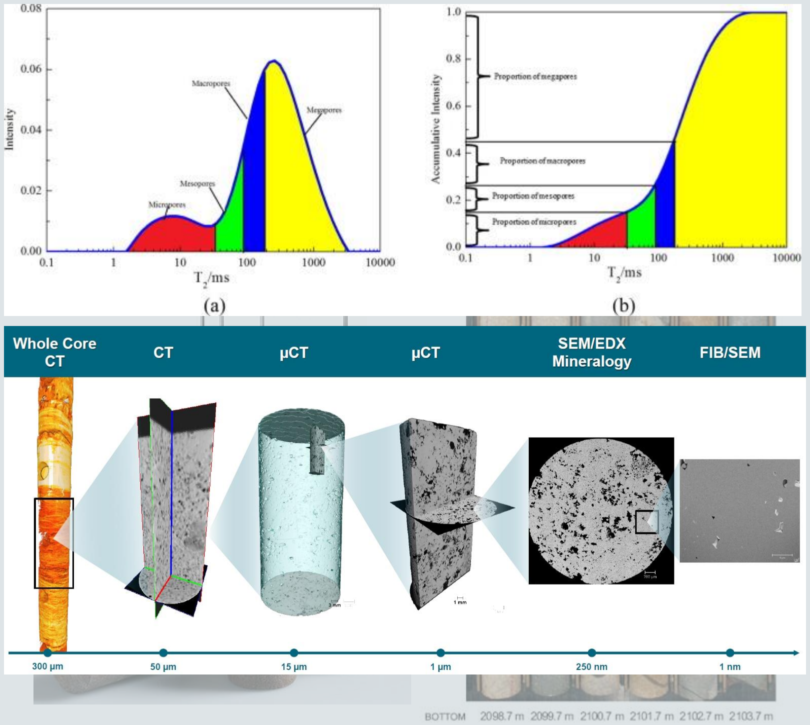
- ✓ Photograph
- ✓ Sedimentology
- ✓ Lithology
- ✓ Stratigraphy

Thin Section

- ✓ Detail Pore Structure
- ✓ Diagenesis
- ✓ Porosity Type
- ✓ Environmental evidence

Small Sample

- ✓ Grain Size Distribution
- ✓ Mineral analysis
- ✓ X-ray and SEM analysis
- ✓ Bio-dating and association



Calibration of Log Interpretation

Routine Core Analysis

- ✓ Porosity
- ✓ Permeability
- ✓ Grain Density
- ✓ As-received saturation

Special Core Analysis

- ✓ Capillary Pressure
- ✓ Relative Permeability
- ✓ Electrical Properties
- ✓ Acoustic Properties
- ✓ Compressive Properties
- ✓ Clay chemistry effects
- ✓ Specific Test

Advance Core Analysis

- ✓ NMR
- ✓ Digital Rock Physics
- ✓ Rock Mechanics
- ✓ Organic content and maturation

Advance and Unconventional Core Analysis

- ✓ NMR
- ✓ Digital Rock Physics
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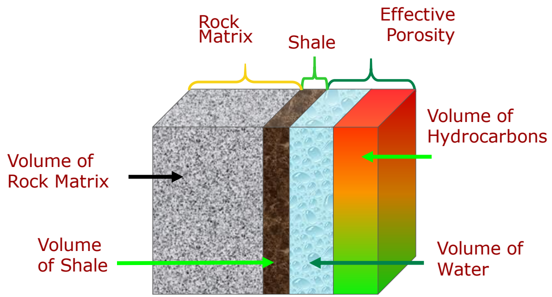
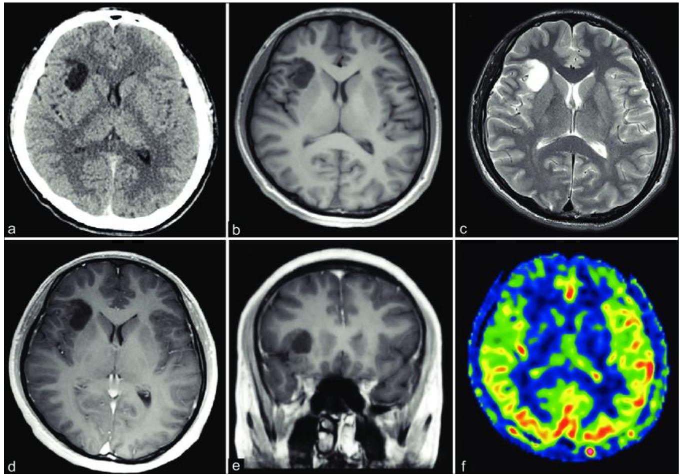
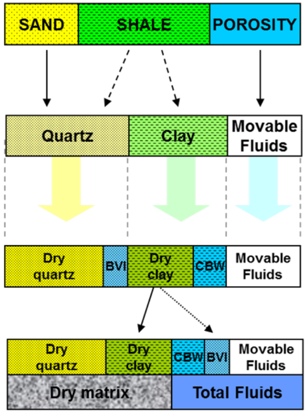
- ✓ Organic content and maturation



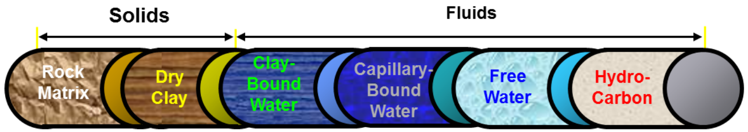
NMR Application in medical



A more more complete model



- Shales make up the bulk of sedimentary formations
- Shales are made up of silt (fine quartz and feldspar) and clay
- The clays have immovable water strongly bound to them (CBW)
- The silts most commonly have capillary water (low permeability)
- CBW is usually very conductive



Advance and Unconventional Core Analysis

- ✓ NMR
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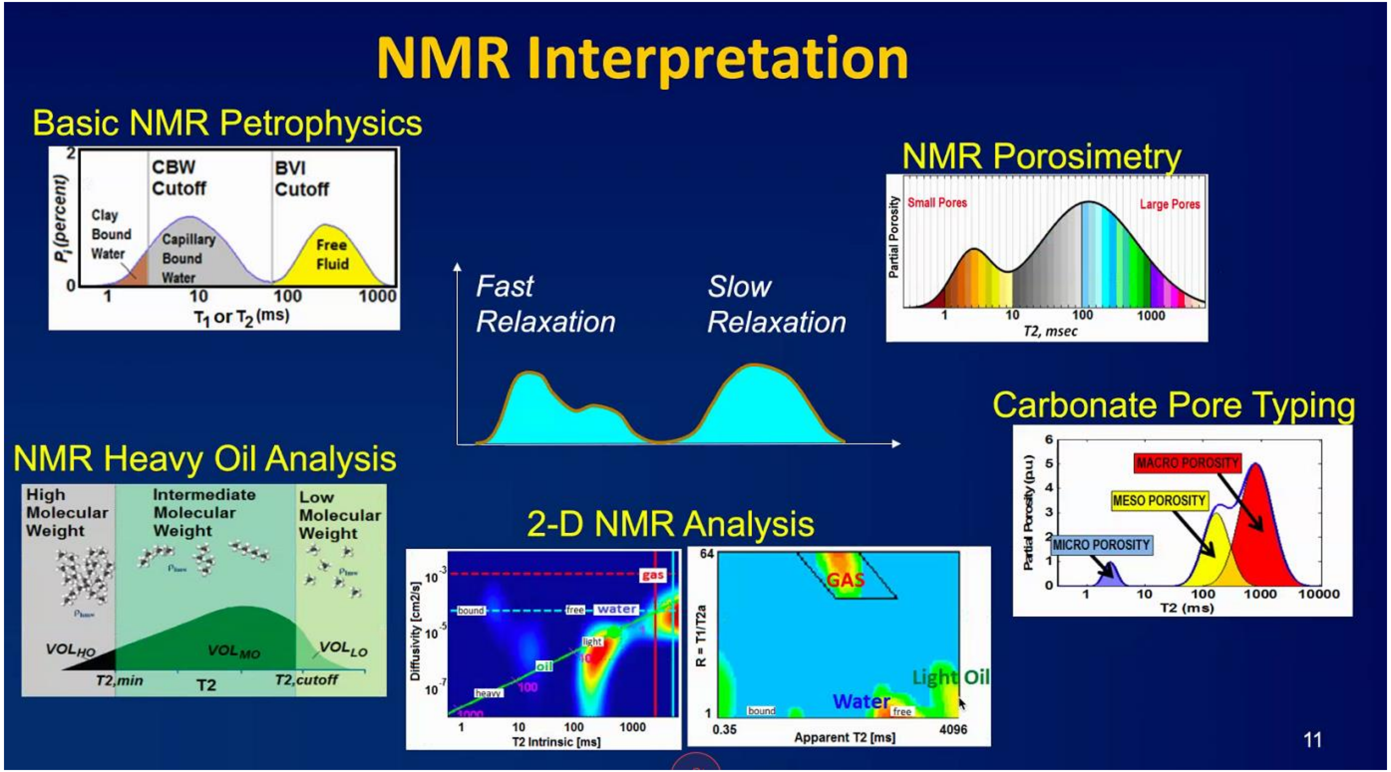
- ✓ Organic content and maturation



Gabor Hursan (2020) . SPE Distinguished Lecturer

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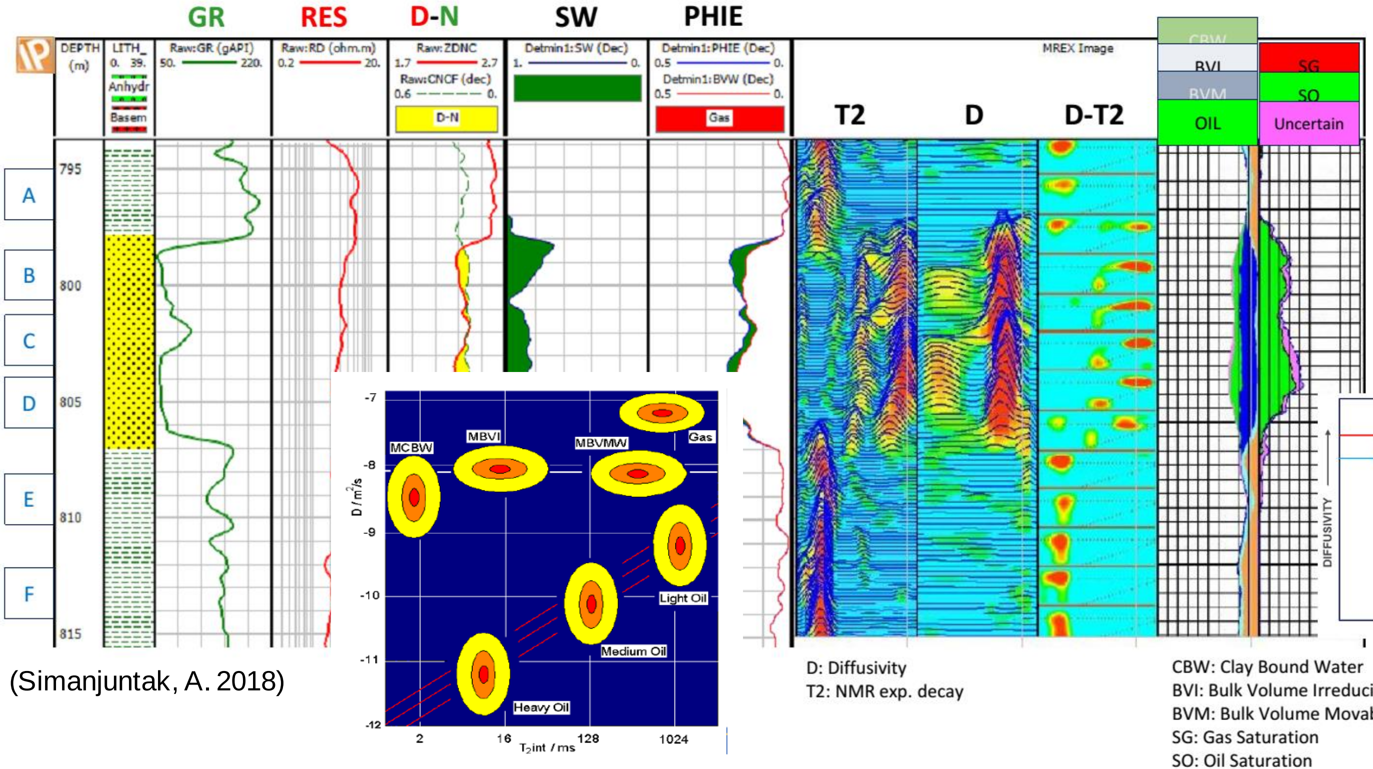

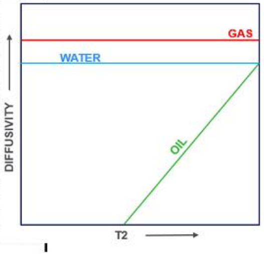

NMR allows:

- Fluid saturation computation independent of resistivity
- Fluid typing
- Movable vs irreducible water
- Porosity independent of lithology effects

(Simanjuntak, A. 2018)

D: Diffusivity
T2: NMR exp. decay

CBW: Clay Bound Water
BVI: Bulk Volume Irreducible (W)
BVM: Bulk Volume Movable (W)
SG: Gas Saturation
SO: Oil Saturation

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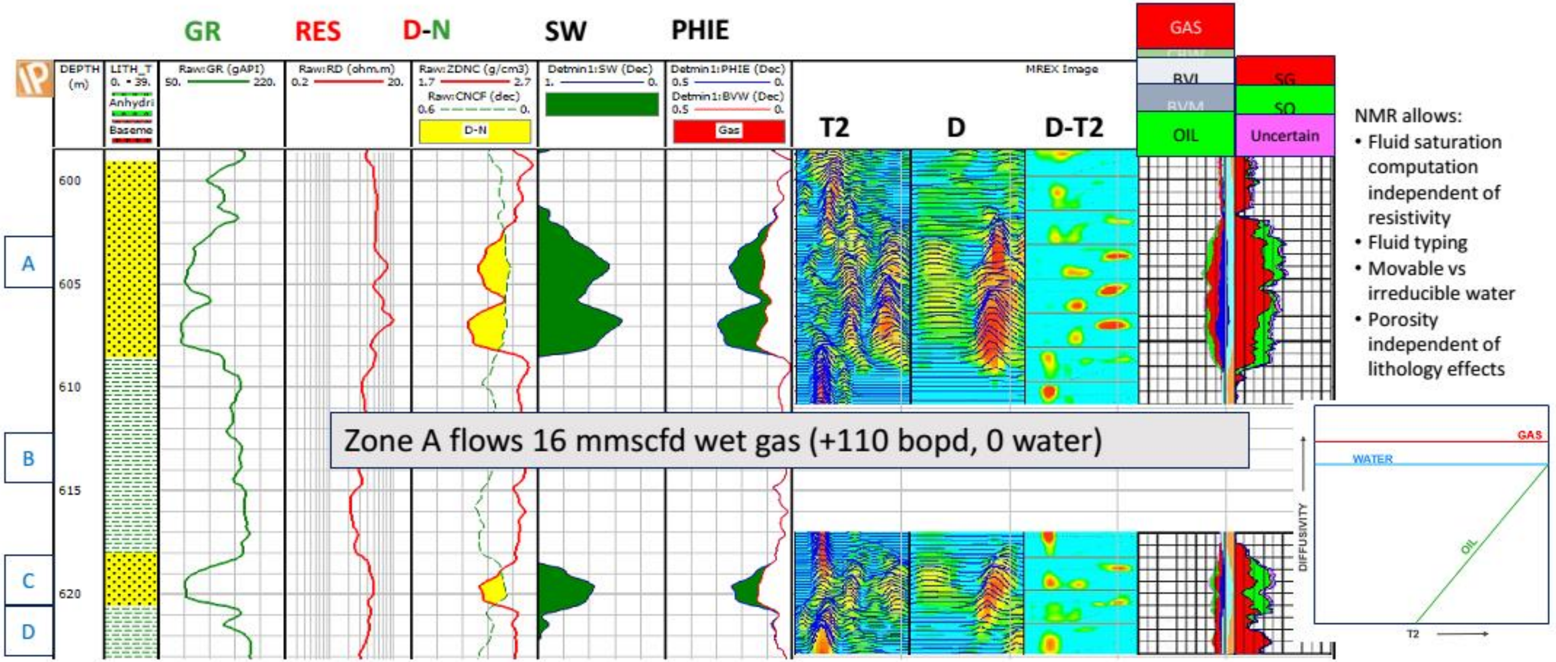

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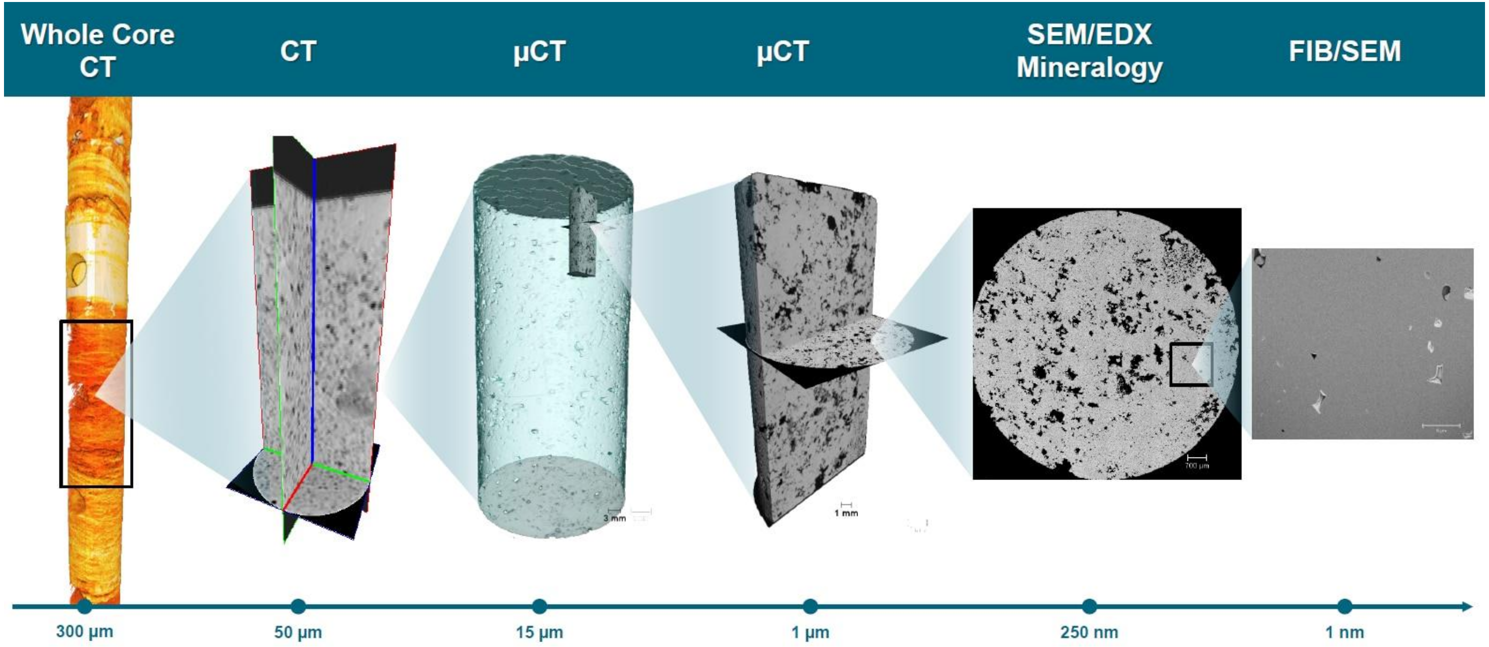
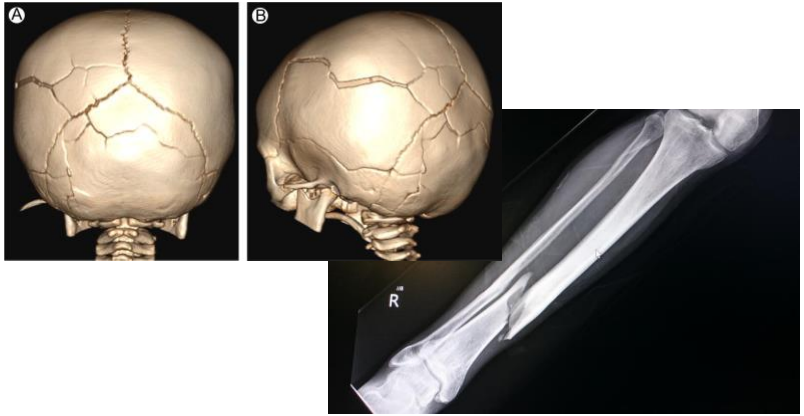
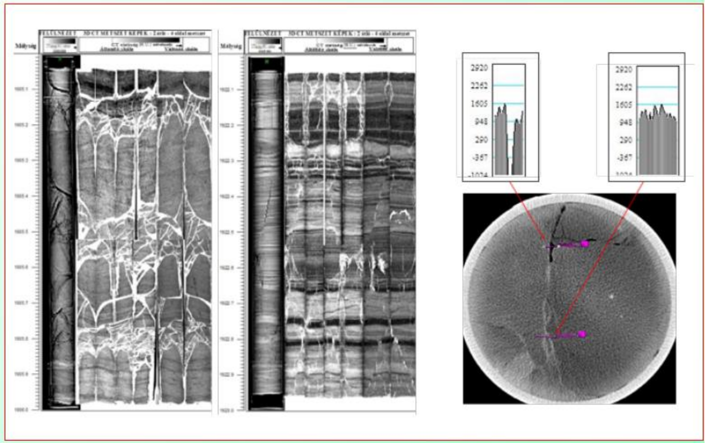
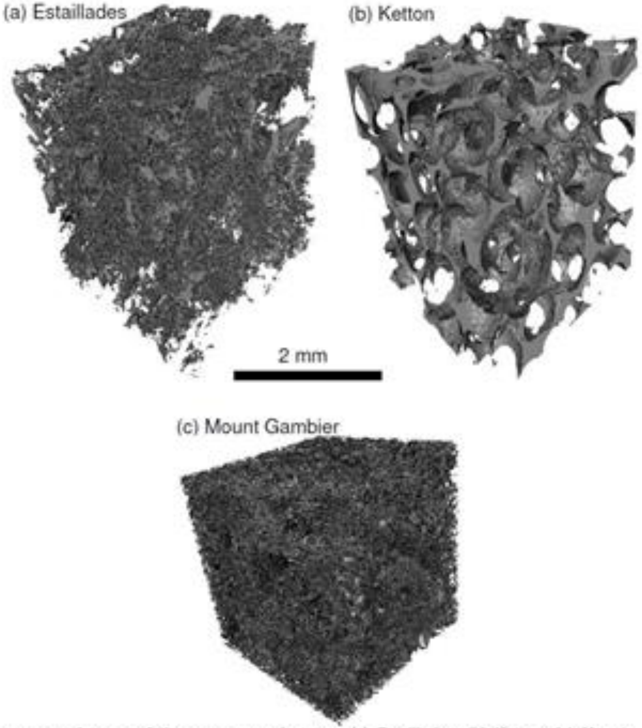


CT Scan

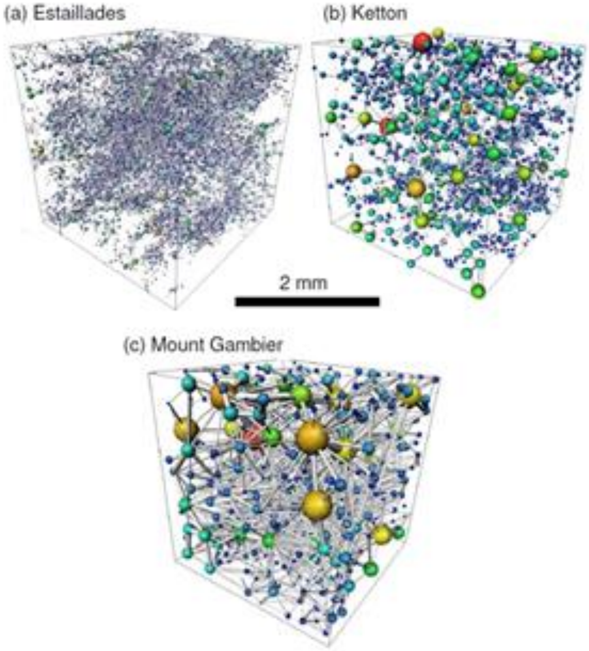




Digital Core Analysis

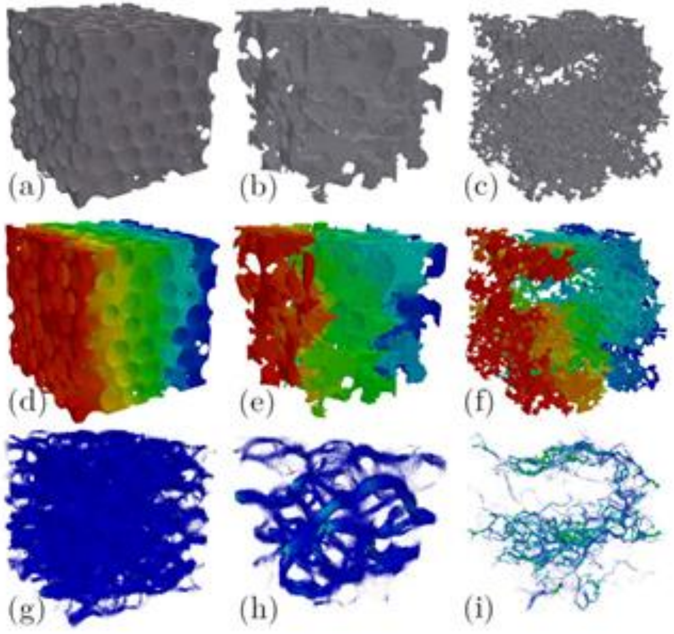


Pore-space images of three quarry carbonates: (a) Estaillades; (b) Ketton; (c) Mount Gambier. The images shown in cross-section in Figures 1(a), (b) and (c) have been binarized into pore and grain. A central 1000^3 (Estaillades and Ketton) or 350^3 (Mount Gambier) section has been extracted. The images show only the pore space.

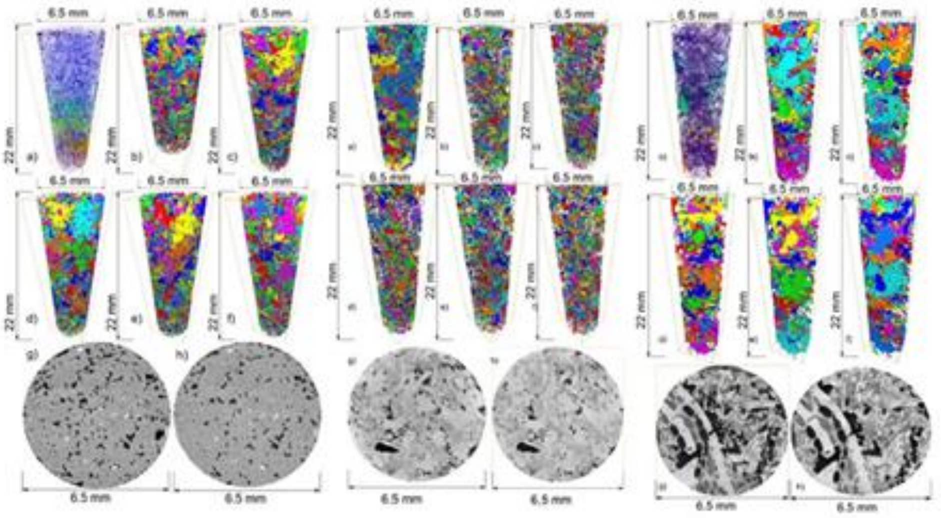


Pore networks extracted from the images shown previously: (a) Estaillades; (b) Ketton; (c) Mount Gambier. For illustrative purposes, only a section of the Mount Gambier network is shown. The pore space is represented as a lattice of wide pores (shown as spheres) connected by narrower throats (shown as cylinders). The size of the pore or throat indicates the inscribed radius. The pores and throats have angular cross-sections – normally a scalene triangle – with a ratio of area to perimeter squared derived from the pore-space image.

Digital Core Analysis



The pore space of the three porous media shown in the previous figure: (a) bead pack; (b) Bentheimer; (c) Portland. Then the pressure field for flow from left to right is shown, with red representing high values and blue low values: flow goes from high to low pressure. The final row illustrates the flow field, with the regions of highest flow indicated. While flow is relatively uniform through the pore space of a bead pack, in the carbonate it is confined to a few tortuous channels (from Bijeljic *et al.*, 2011).



Three-dimensional rendering of CO_2 after brine injection. Each unique CO_2 ganglion is displayed as a different colour. Each ganglion is isolated, and so is trapped. Left Bentheimer sandstone, middle Estaillades limestone, right Mount Gambier limestone. The results from five experiments from each rock type are shown: the top left image shows the fluid distribution after primary drainage, while the other five are shown after waterflooding. The bottom row shows two-dimensional slices of the raw images. From Andrew *et al.* (2014).

Advance and Unconventional Core Analysis

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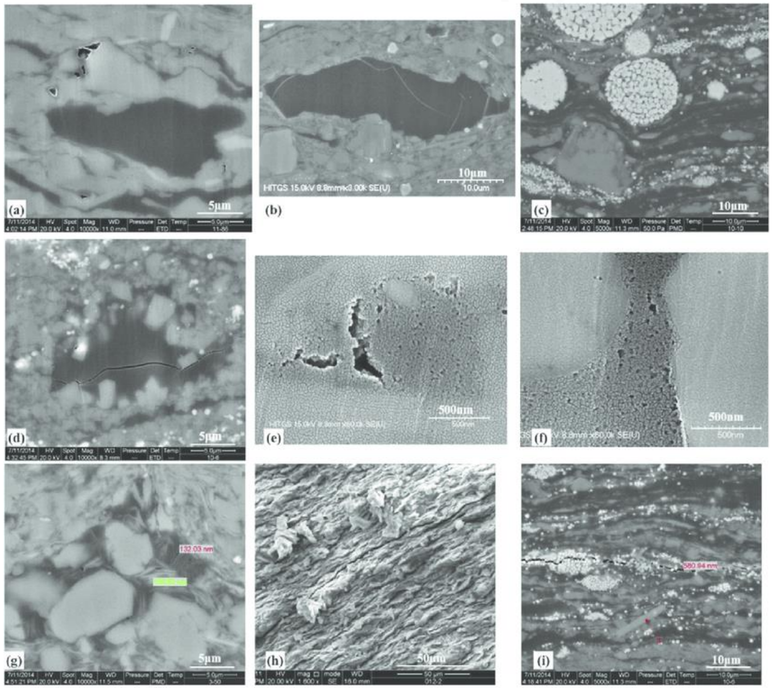

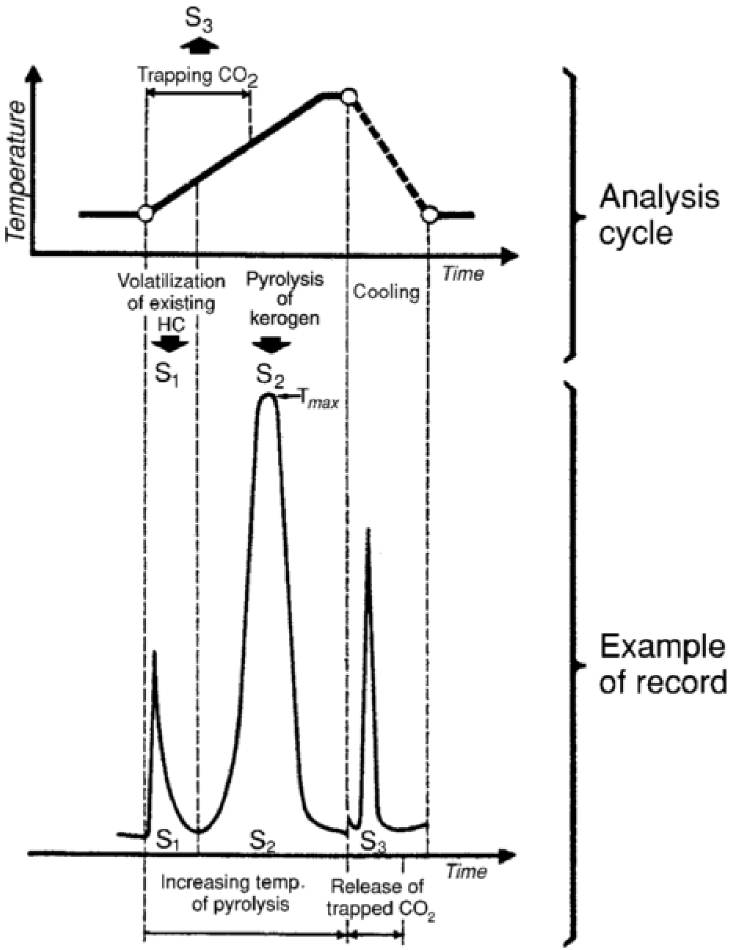

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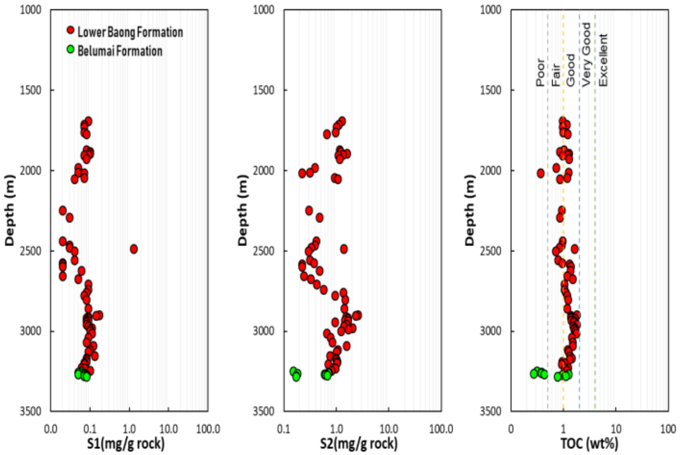
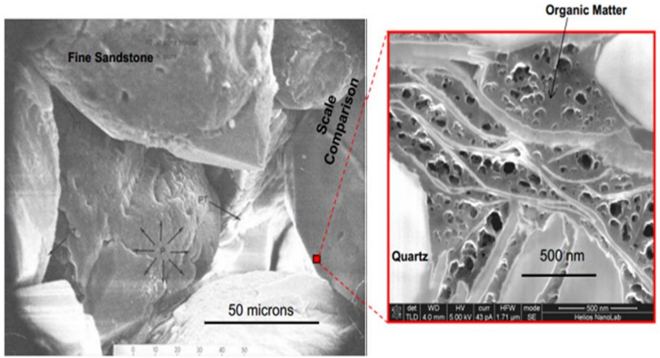
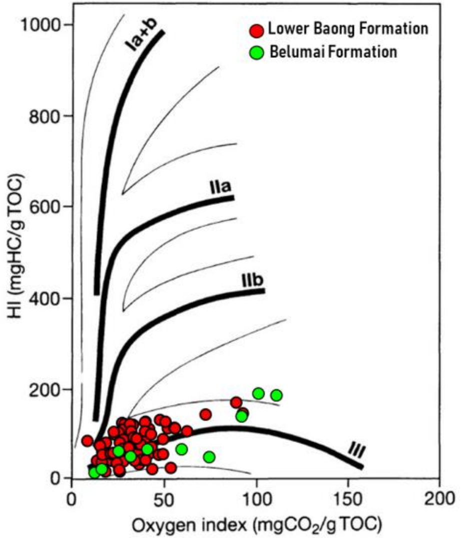
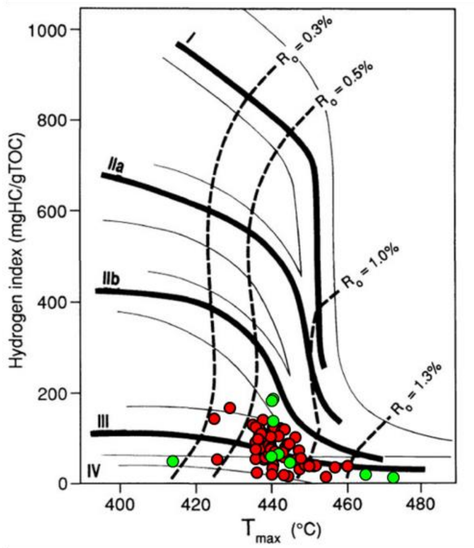


Quality	TOC (w%)
Poor	<0.5
Fair	0.5 to 1
Good	1 to 2
Very good	2 to 4
Excellent	>4

Thermal maturation	Ro
Inmature	<0.6%
Oil window	0.6-1.1%
Wet gas window	1.1-1.4%
Dry gas window	1.4-~3.2%
Gas destruction	>~3.2%







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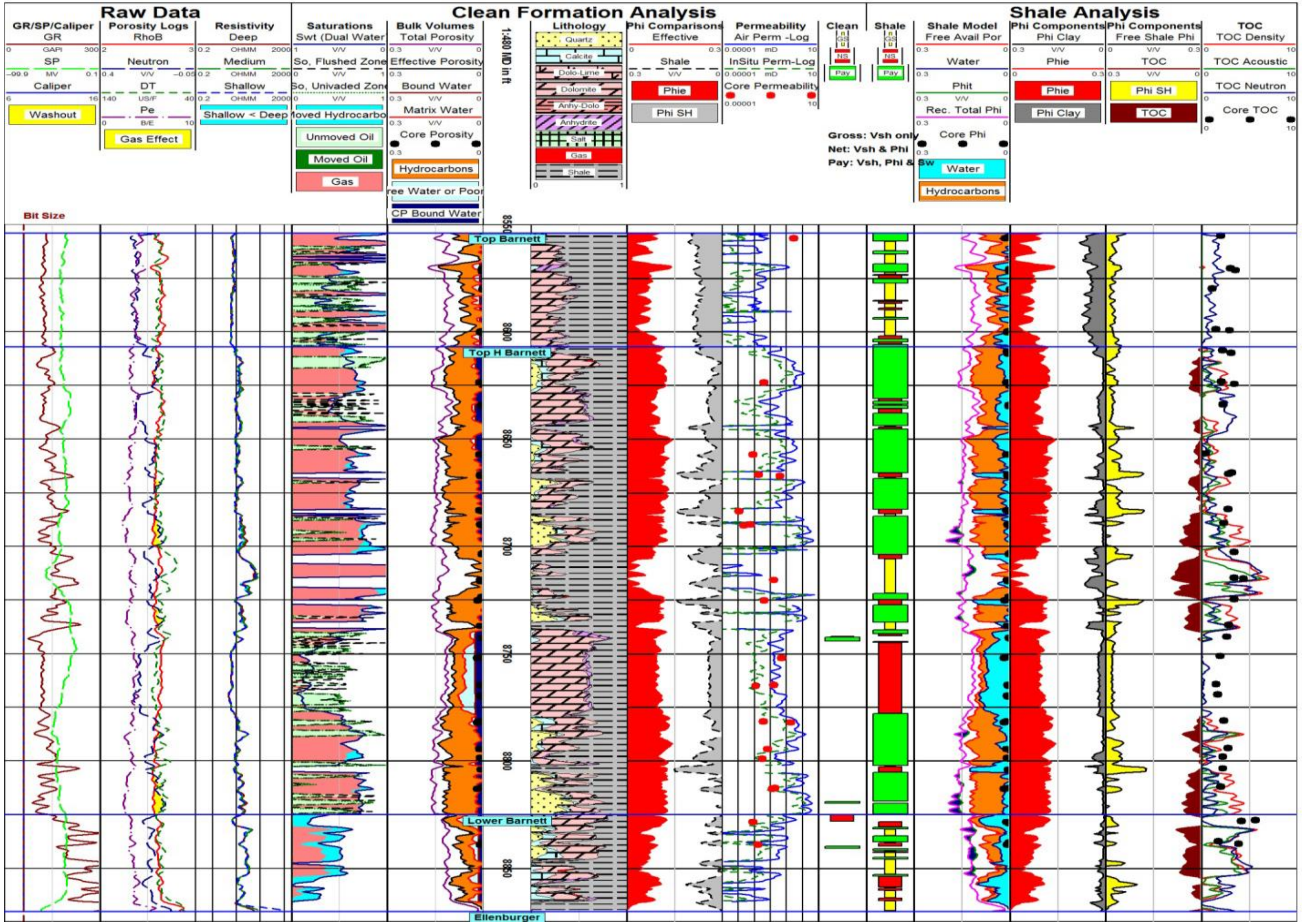

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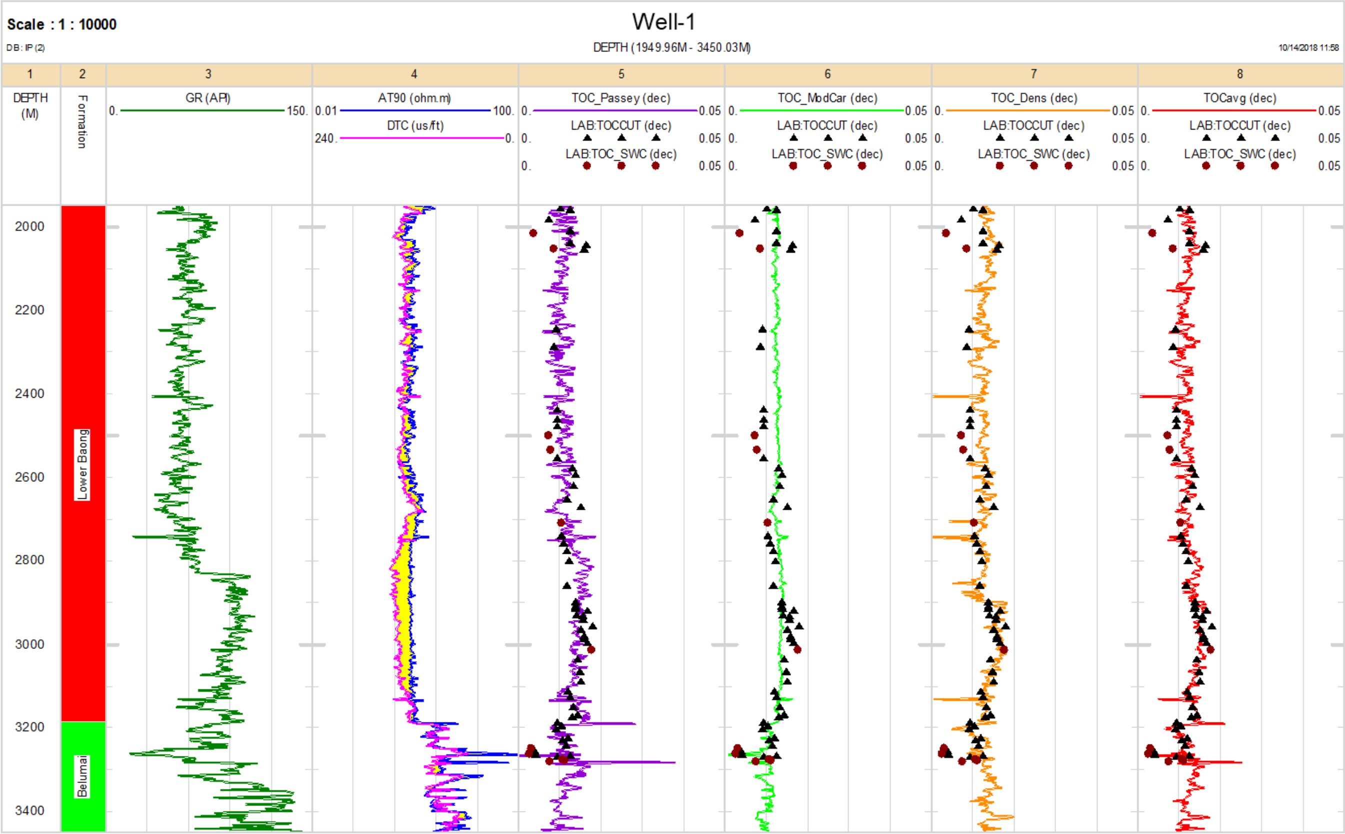

THANK YOU FOR YOUR ATTENTION!

"Petrophysics an exotic earth science, poorly understood and rarely appreciated in the oil and gas industry"

Koko Kyi - Petrophysicist

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