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SPEAKER

2020 – 2021

An Integrated Petrophysical Evaluation for Reservoir Characterization and Modeling of Field Development

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3rd February 2021

SPWLA Global Distinguished Speaker

SOCIETY OF PETROPHYSICISTS AND WELL LOG ANALYSTS

Outline

- Introduction & Challenges
- Integrated Reservoir Characterization Workflow
- Porosity, Permeability and Saturation In Cored Wells
- Reservoir Rock Type and Saturation Height Model
- Fluid Contacts and Calculation Technique
- Evaluation Results
- Conclusion

Introduction and Challenges

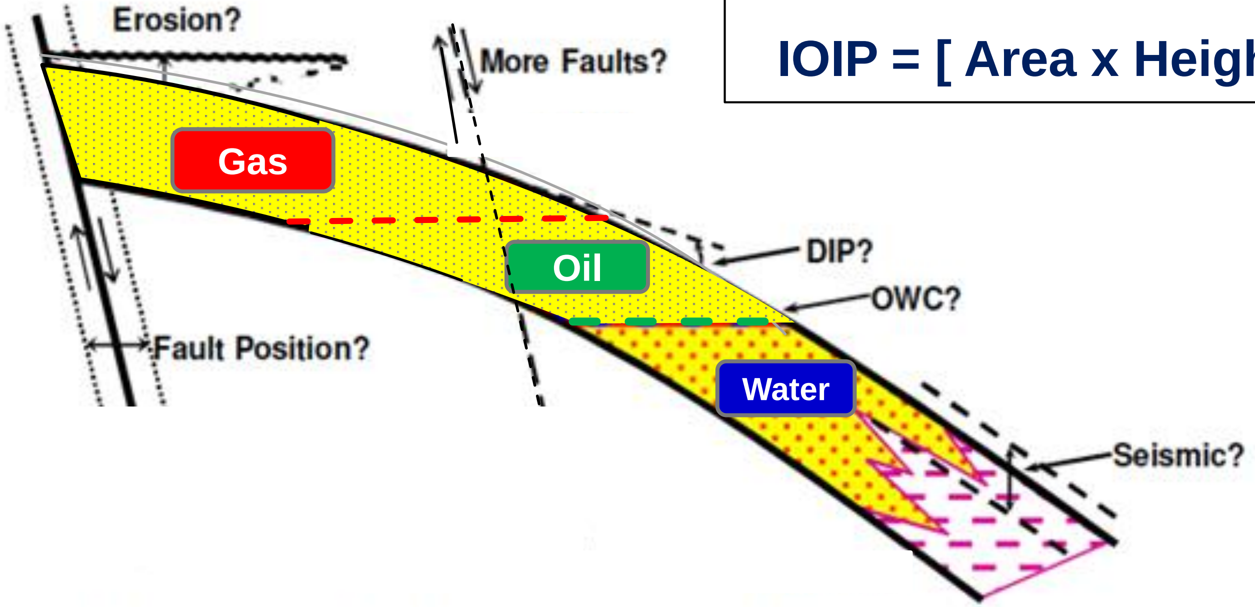
- The uncertainty of original oil in place (OOIP) is one of challenges in the reliable reservoir characterization and reservoir development.
- Multi fluid contacts, major-minor faults, variation of water saturation resistivity with SWI of core saturation height model and production data.
- It requires an integrated petrophysical evaluation approach of logs, special core analysis (SCAL), geology, geophysics, reservoir rock typing (RRT), saturation height model (SHM) and detailed reservoir/fluid analysis to provide reliable reservoir characterization and fluid contacts estimation.
- An integrated Permeability, RRT and SHM to be developed from porosity, clay bound, pore size, core and mobility data for reliable reservoir modeling of field development.

Hydrocarbon Volume Uncertainties

IGIP = [Area x Height x Porosity x Sg] / Bg

&

IOIP = [Area x Height x Porosity x So] / Bo

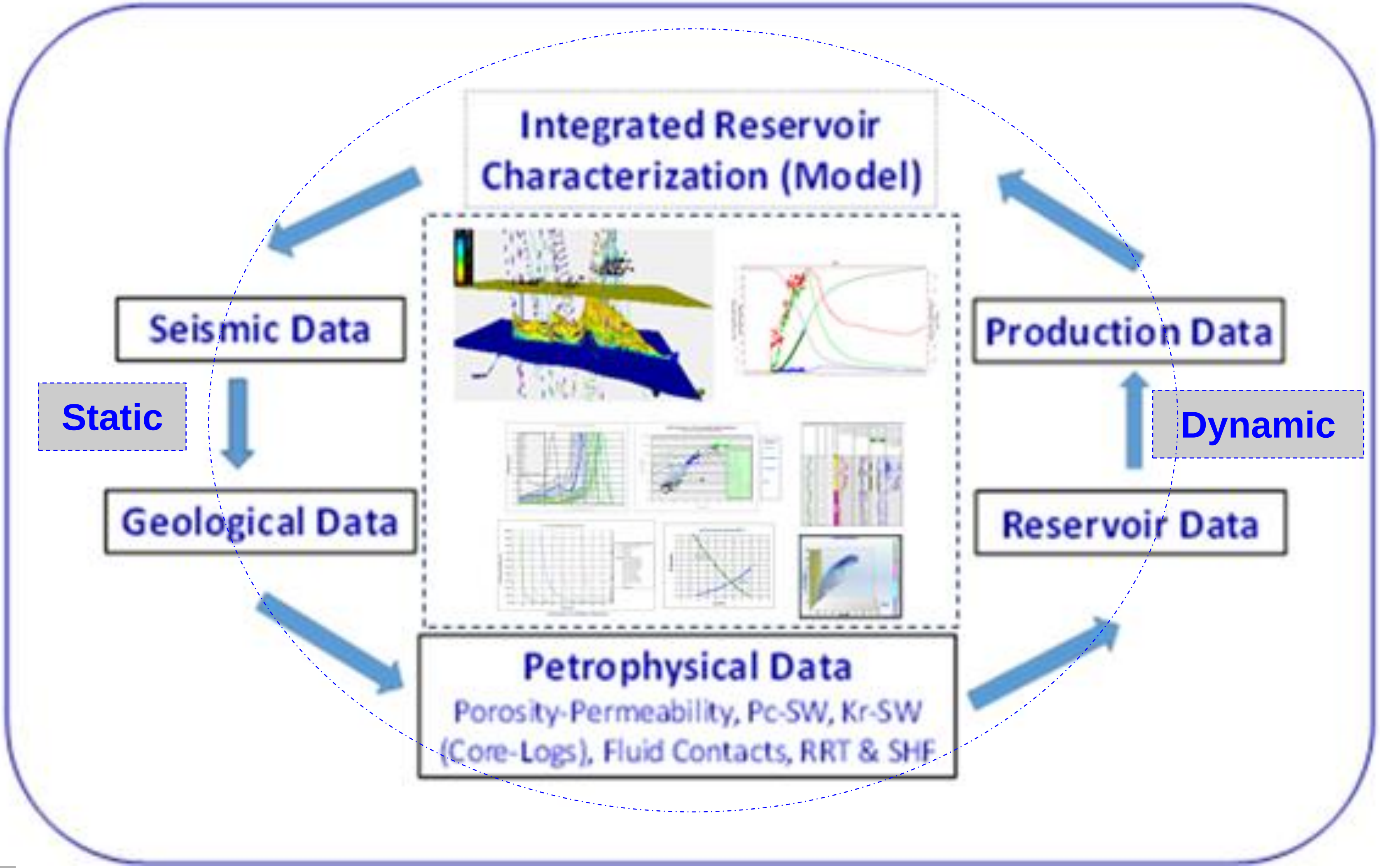


Remarks:

Gas Volume in SCF with 43560
Oil Volume in STB with 7758
Area in Acres
Height in Feet
Porosity in v/v
Saturation in v/v
Gas Volume Factor in FT^3/SCF
Oil Volume Factor in BBL/STB

STRUCTURAL	STRATIGRAPHIC	ACCUMULATION	PROPERTIES
Dip Error	Rock Development	Position Contacts	Porosity
Seismic Error	Erosion	Possible Gas Cap	Saturation
Fault Position			Net/Gross
Additional Faulting			Formation Volume Factors

Integrated Reservoir Characterization Workflow Approach

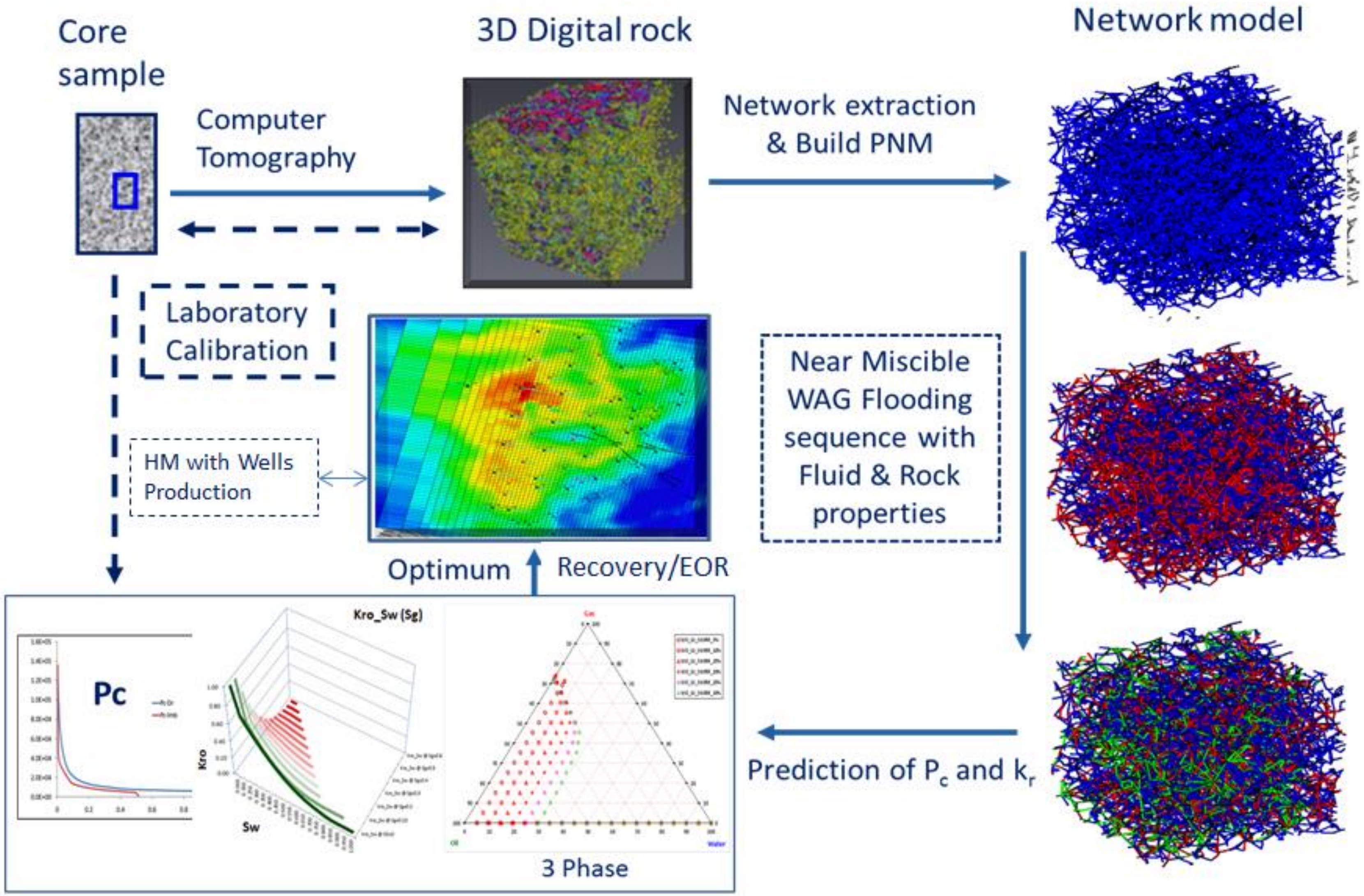


SPE-198634 & SPE-198636

Integrated Petrophysical Evaluation

- Calibrate Log Porosity with corrected core porosity.
- Use SCAL data of cementation exponent (m) and saturation exponent (n) for water saturation.
- Generate Permeability Log as function of porosity, bound water-clay, pore throat & diagenesis.
- Use Core Porosity and Permeability Distribution Data for reservoir rock type (RRT).
- Use Pore throat size and Distribution (MICP) for RRT.
- Use Capillary Pressure (Pc) and Water Saturation (SW) of SCAL_Porous plate for RRT.
- Use Formation Pressures, Fluid Contacts, Gradients and Well test data.
- Build Saturation Height Function (SHF) for every RRT.
- Integrate core, logs and reservoir data for reservoir rock typing (RRT) and Saturation Height Function (SHF).
- Implement RRT and SHF in Reservoir Modeling (Static and Dynamic).

Digital Rock Physics and Pore Network Model (AI) for EOR



SPE-188298

Petrophysical Evaluation Approach

- In petrophysical evaluation the core (SCAL) has been used for input parameters.

  a = 1, m = 1.84, n = 1.75 (NOB @ 1500 psi) shallow reservoir condition.

  a = 1, m = 1.85, n = 1.70 (NOB @ 3700 psi) deep reservoir condition.

- Formation water salinity:

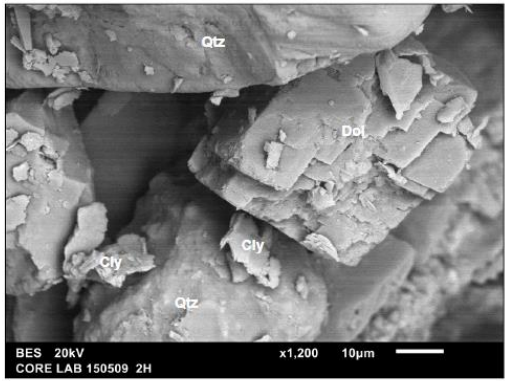
  Shallow reservoirs: 195-210 PPK from formation water analysis & formation pressure gradient 0.495-0.5 psi/ft.

  Deeper reservoirs have lower formation water salinity: 80-120 PPK.

- Water Saturation Computation (Clean, Non-Clean & Pressure-Temperature Effect)
- Permeability Computation (Poro-VCL-PTR, Core).
- Reservoir Rock Typing (Poro-Perm, PTR, Pc_SW, Kr_SW & Core-logs).
- Fluid Contacts Evaluation (Logs, Formation Pressure, Reservoir system and SHF).
- Saturation Height Function (SHF: Core-Logs-FP).

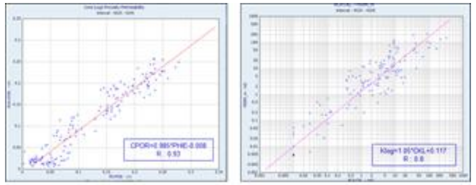
Core, Logs and Fluid Data Evaluation

Core Data
RCA: Porosity, Permeability
SCAL: m,n, CEC, Pc-Sw, Kr
at reservoir condition (P/T)
SEM/XRD & RM

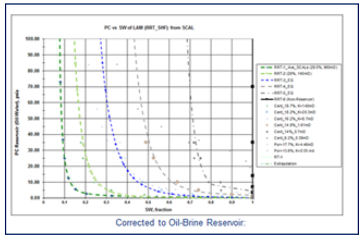


Petrophysical Evaluation

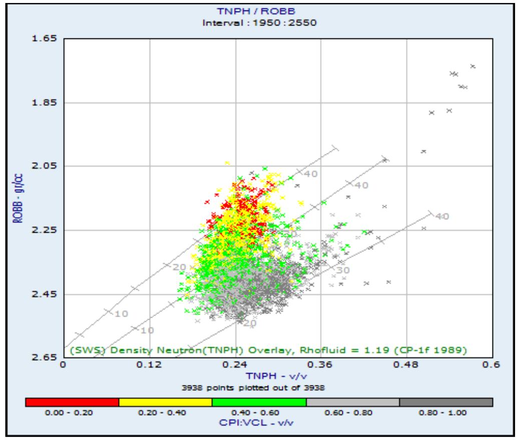
- Core & Logs Calibration
- Mineral Volume, Porosity, Permeability
- Saturation and Fluid Contacts
- Reservoir Rock Typing
- Saturation Height Model (Pc-Sw)

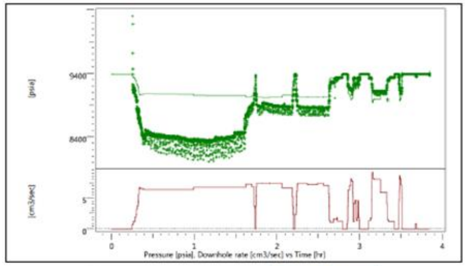


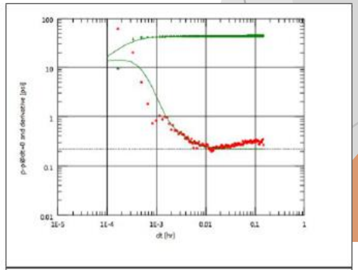
		Whole Rock Mineralogy (Weight %)											Clay (Phyllosilicate) Mineralogy (Weight %)				
Plug No.	Depth (m)	Quartz	K-Feldspar	Plagioclase	Calcite	Dolomite	Siderite	Pyrite	Amphibole (Mg-Hornblende ?)	Barite	Halite	Total Clay	Smectite or highly smectitic Illite/Smectite	Illite & Mica	Kaolinite	Chlorite	S in I/S
2H	1930.48m	47.6	5.8	11.6	12.0	1.7	0.0	0.6	1.4	0.0	0.0	19.4	0.3	5.7	1.4	12.0	>75% (?)
3H	1930.52m	47.9	4.1	11.3	13.2	2.2	0.0	0.0	0.8	0.0	0.3	20.1	0.4	5.7	1.6	12.5	>75% (?)
7H	1933.53m	44.6	6.4	13.0	9.4	1.0	0.0	0.0	0.2	1.0	0.5	23.9	0.1	9.4	3.3	11.1	>75% (?)
8H	1933.62m	50.6	6.7	12.3	10.9	1.1	0.0	0.0	0.1	0.0	0.0	18.2	0.1	6.9	1.1	10.1	>75% (?)
9H	1937.47m	36.2	8.6	12.4	16.8	1.4	0.0	0.3	0.7	0.0	0.4	23.2	0.3	9.5	1.5	11.9	>75% (?)
10H	1937.55m	32.2	5.1	10.9	35.8	0.0	0.0	0.0	0.4	0.0	0.0	15.7	0.2	6.4	1.2	7.8	>75% (?)

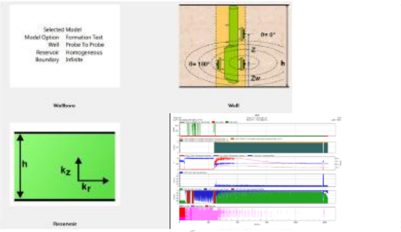


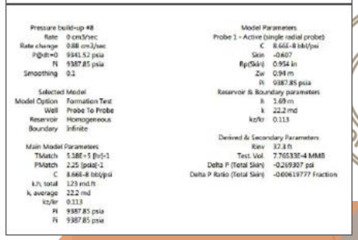
Well Logs Data
Porosity, SW, Permeability, Formation Pressure & Fluids Sampling





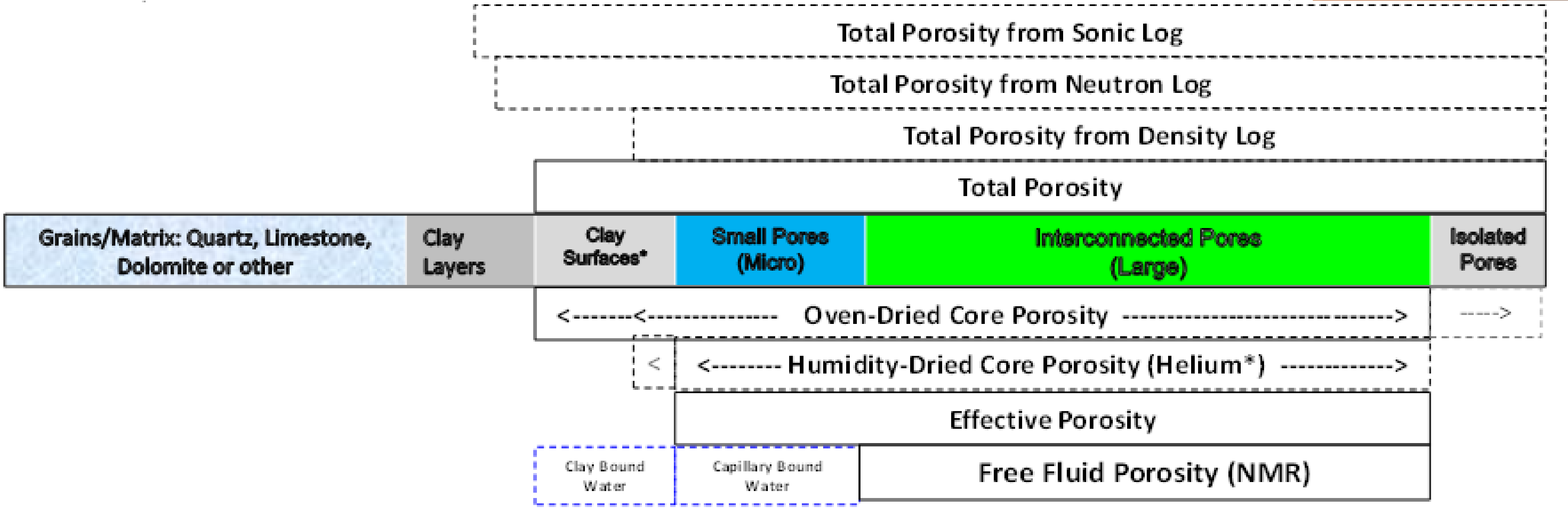






Fluids & Gas
PVT/Production Data

Core Porosity and Log Porosity



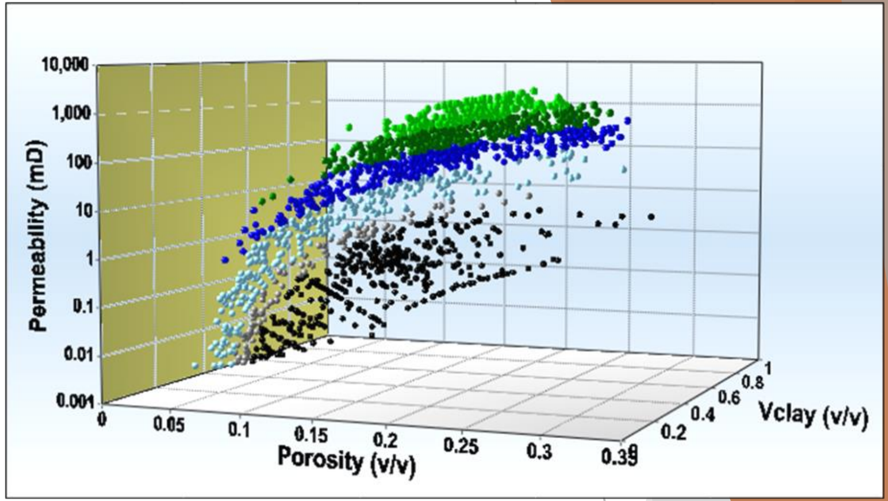
Irreducible water saturation increases with decreasing of pore throat size (radius) and/or capillary bound effects.

SPE-198634 & SPE-198636

Permeability Approach in Sandstone Reservoir

Permeability Equation (Core-Logs).

Permeability = (a*100000*Porosityb)/(10**(c*Vclay))**



With :
a=1.2 or (0.9 – 1.5)
b=3.5 or (3 - 4)
c=4.5 or (4 – 5)

Permeability is calibrated with NOB corrected of core data L-X (shallow reservoir) & L-Y (deep reservoirs).
Formation pressure mobility is used to compare it qualitatively.

The advantages of this permeability relationship:

- It will give permeability ranges considering porosity and volume of clay.
- It is following the real ranges of core's porosity-permeability & mobility of formation pressure
- It represents reservoir heterogeneities

SPE-198634

Permeability Approach in Carbonate Reservoir

Permeability = (a*100000*Porosityb)/(10**(c*v)) + d**

Where:
a = 1.0 or (0.8 - 1.2)
b = 5.0 (Y-A), 4.5 (Y-CD), for high perm b = 4.2 & for low perm b = 6
c = 5.0 or (4.5 - 5.5), cementation
v = clay & bound water constant
d = diagenetic & dolomite constant

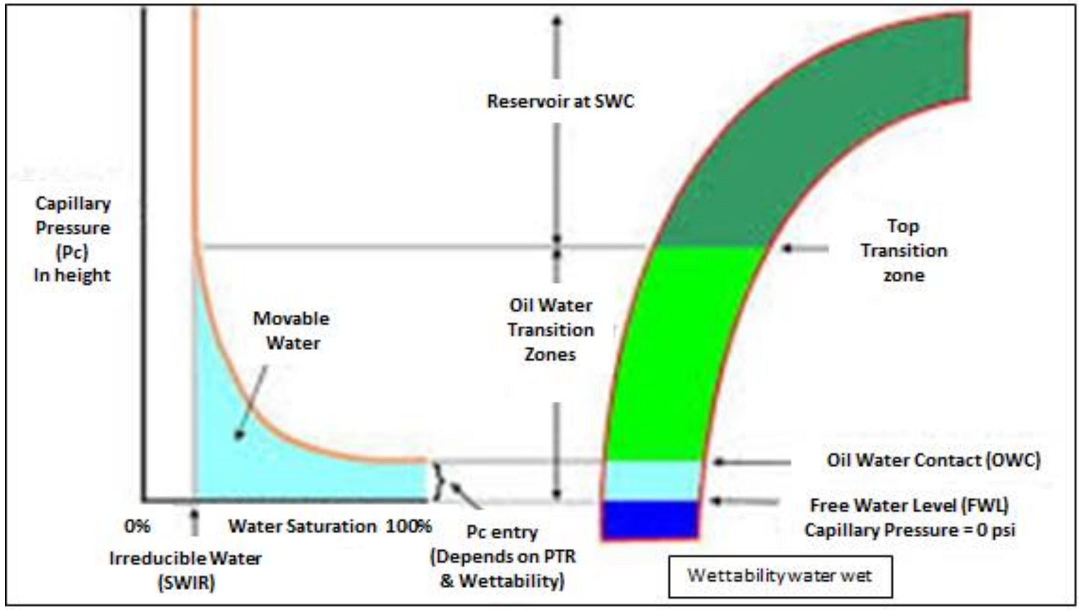
Permeability is calibrated with NOB corrected of core data. Formation pressure mobility is used to compare it qualitatively.

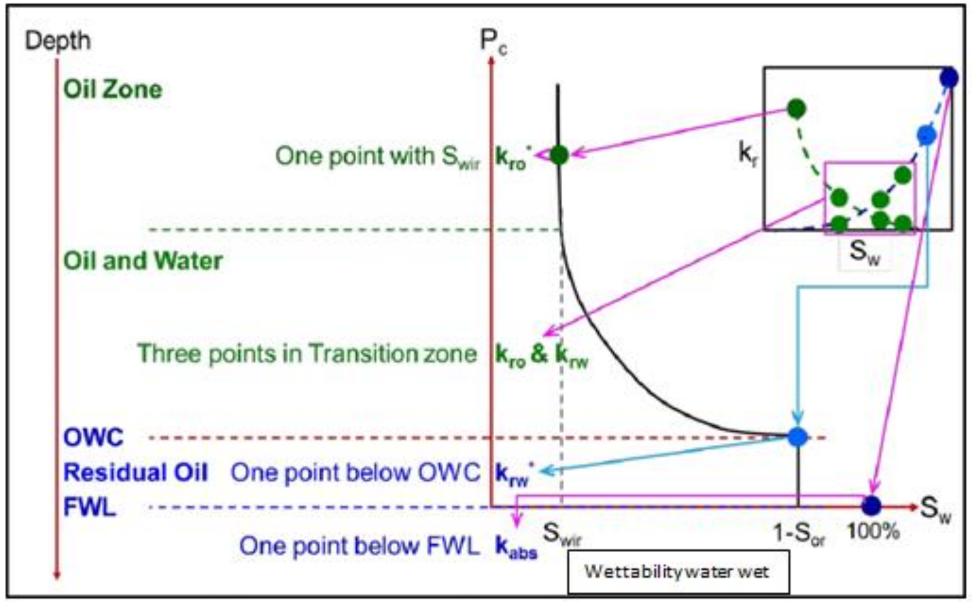
The advantages of this permeability relationship:

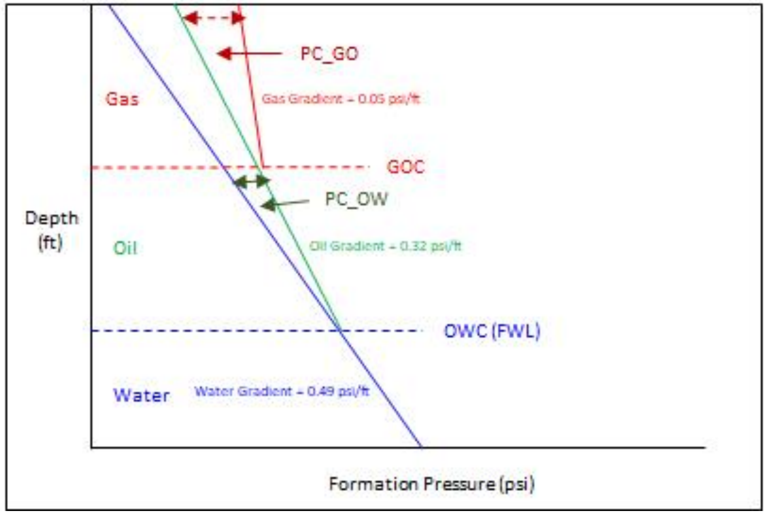
- It will give permeability ranges considering porosity, clay/bound water, cementation and diagenetic.
- It is following the real ranges of core's porosity-permeability & mobility of formation pressure
- It represents reservoir heterogeneities

SPE-198636

Capillary Pressure, Water Saturation and Relative Permeability



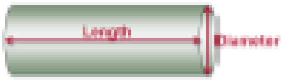




Relative Permeability

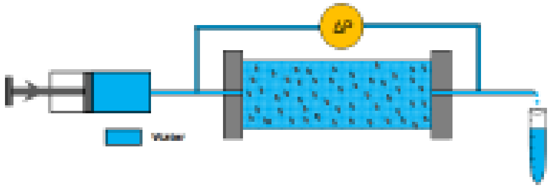
- **Permeability** – The measure of the ability of a porous material to transmit a fluid

  $K = q * \mu * L / A * \Delta P$ units: (cm^3/s) (cp) (cm) / (cm^2) (atm)

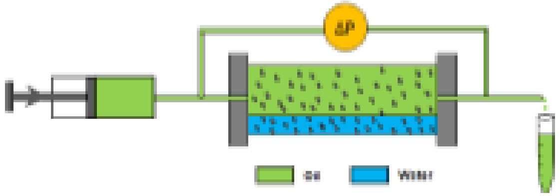


- **Specific Permeability** – Permeability determined with only one fluid present in the pore space - K_w, K_o, K_g

  $K_w(mD) = q_w * \mu_w * L * 1000 / A * \Delta P$



- **Effective Permeability** – Permeability to one fluid with more than one fluid present in the pore space - K_{eo}, K_{ew}, K_{eg}

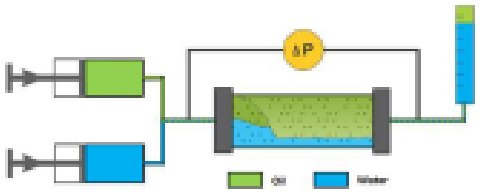


- **Relative Permeability** – Effective Permeability divided by 'Base' Permeability, K_{base} (base permeability usually measured at the beginning of the experiment e.g. k_w, $K_o(Swi)$)

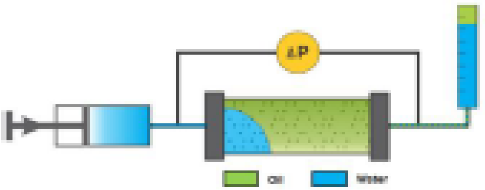
$K_{ro} = K_{eo} / K_{base}$

$K_{rw} = K_{ew} / K_{base}$

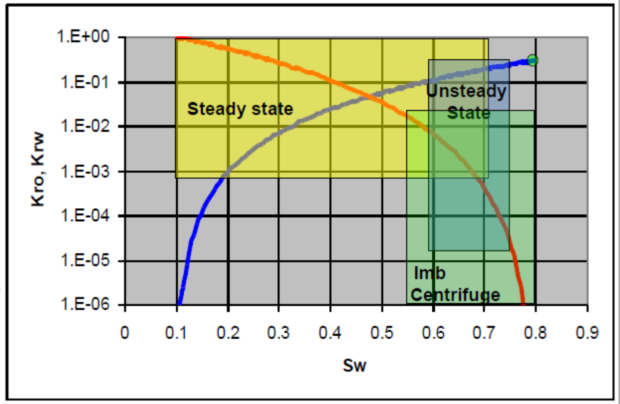
$K_{rg} = K_{eg} / K_{base}$



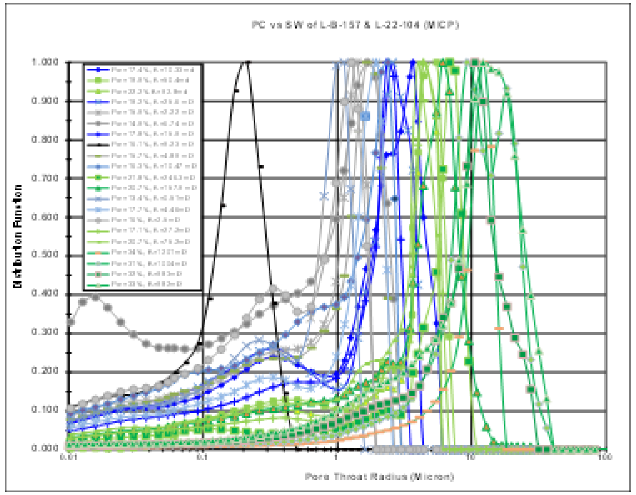
Steady State

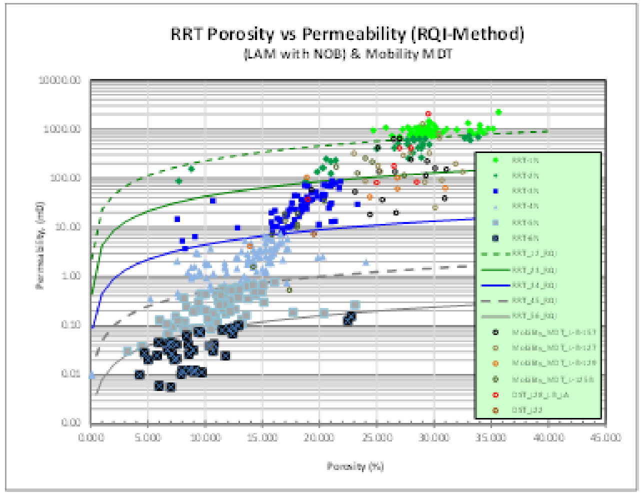


Unsteady State



Reservoir Rock Type and Saturation Height Model





Facies :

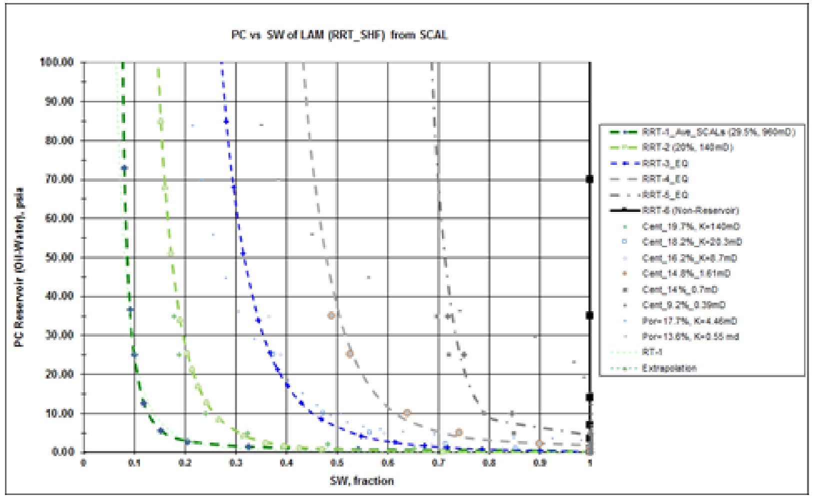
Channel

Crevasse

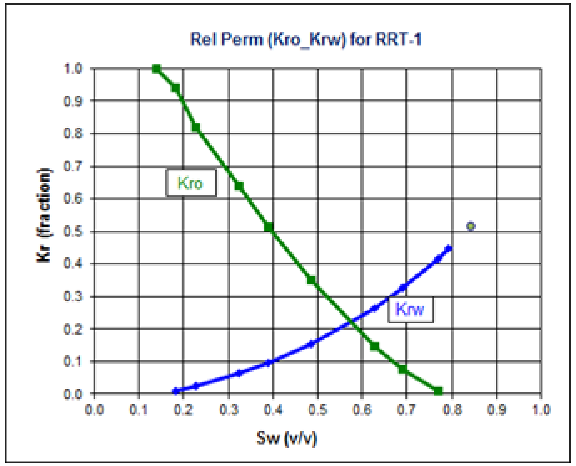
Overbank

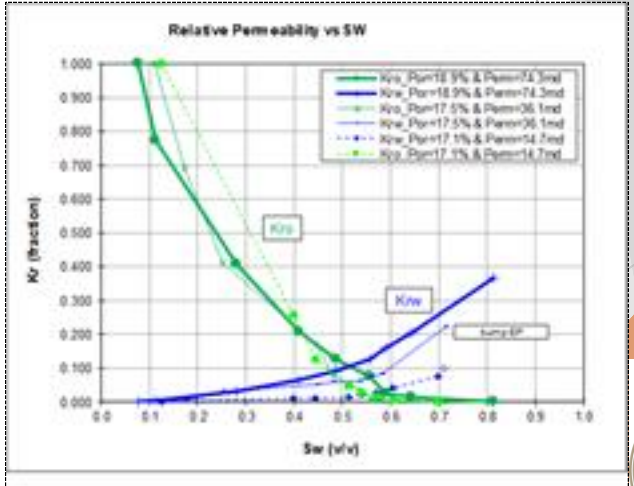
Mud

RRT & Sor



Corrected to Oil-Brine Reservoir:





Swir: 0.08 to 0.12 v/v
Sor: 0.2 to 0.3 v/v

Drainage for SWI - - - - - - - - - - - - - - - - - - > Imbibition for Sor

Saturation Height Function for Every Reservoir Rock Types

$$SW\_RRT = \left[\frac{\left(\dfrac{a}{Water\_gradient - Hydrocarbon\_gradient}\right)}{\dfrac{(HAFWL\_m * 3.28)}{\left(\dfrac{Permeability\_mD}{Porosity\_fraction}\right)^{0.5}}}\right]^{(\frac{1}{b})}$$

RRT-1		RQI Range	RRT-2		RQI Range	RRT-3		RQI Range	RRT-4		RQI Range	RRT-5		RQI Range	RRT-6	RQI Range
a	1.5		a	1		a	2		a	0.75		a	0.125		SW=1	Non reservoir
b	3	RRT1 >= 1.5	b	4.1	1.5>RRT2 >= 0.65	b	4.5	0.65> RRT3 >=0.21	b	7	0.21> RRT4 >=0.07	b	19.5	0.07> RRT5 >=0.028	SW=1	RRT6<0.028

Water Gradient : 0.495 psi/ft
Oil Gradient : 0.320 psi/ft
HAFWL : Height above free water level, ft
Pc (psi) = Diff Water and Oil Gradient * HAFWL (ft)

a is constant IFT and contact angle for every RRT
b is constant saturation and entry pressure for every RRT

Where:

SW_RRT is water saturation of reservoir rock type (v/v)

HAFWL is height above free water level (m)

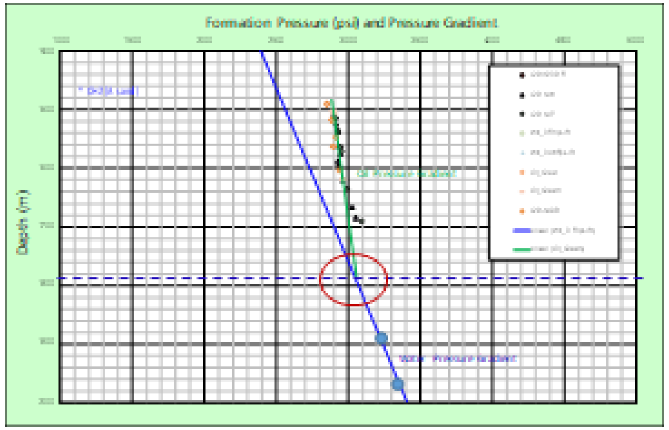
Perm is Permeability (mD)

Porosity unit is v/v

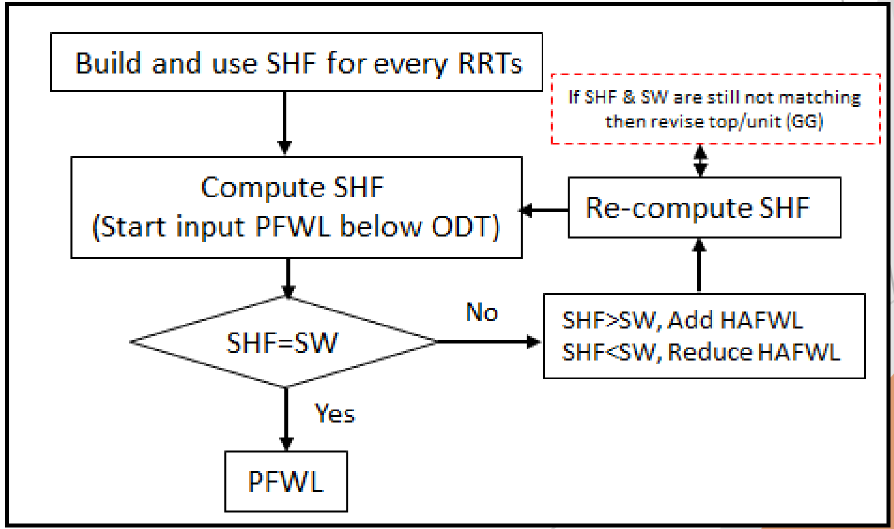
It is recommended to use SHF for every RRT and to avoid normalized SHF, details can be found in SPE-198634

Reservoir Fluid Contacts and Calculation Technique

- Reservoir fluid contact, free water level (FWL) is determined by formation pressure gradients (Gas-Water or Oil-Water) and the logs are used to confirm the fluid contacts.
- When only oil down to (**ODT**) or gas down to (**GDT**) can be identified from the well logs then:
  - ODT or GDT of well logs at original condition can be used to calculate possible free water level (PFWL) or current oil water (OWC) contacts for depletion case.
  - It is important to solve fluid contacts (oil-water or gas-water) for reservoir model with many reservoir units and compartmentalized reservoirs.
  - Calculation technique with SHF, RRT and SW are used for this purpose.

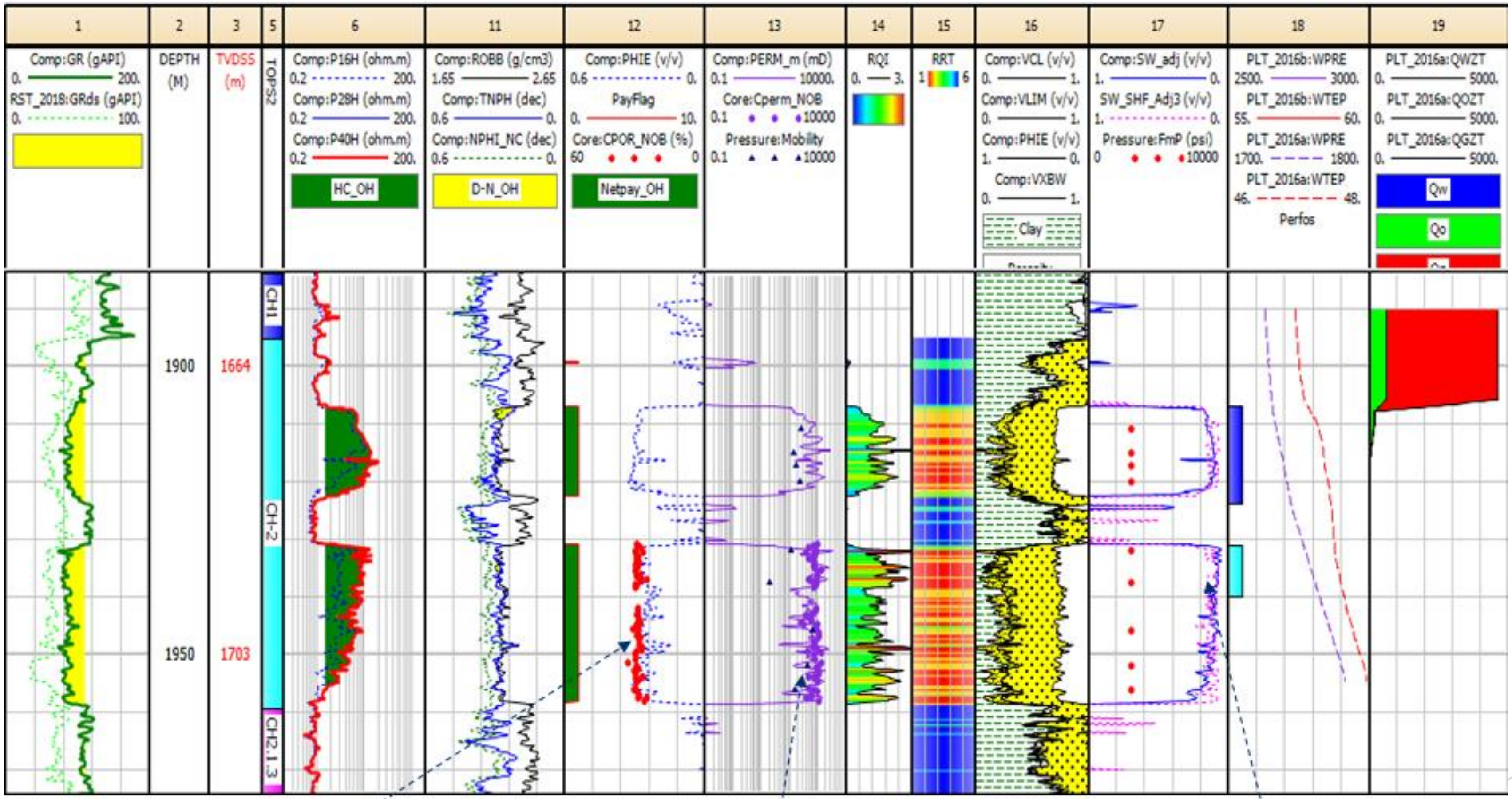


FWL from formation pressures & logs data



In keys original wells

RRT, SW Logs & Saturation Height Model (Cored Well L-X)

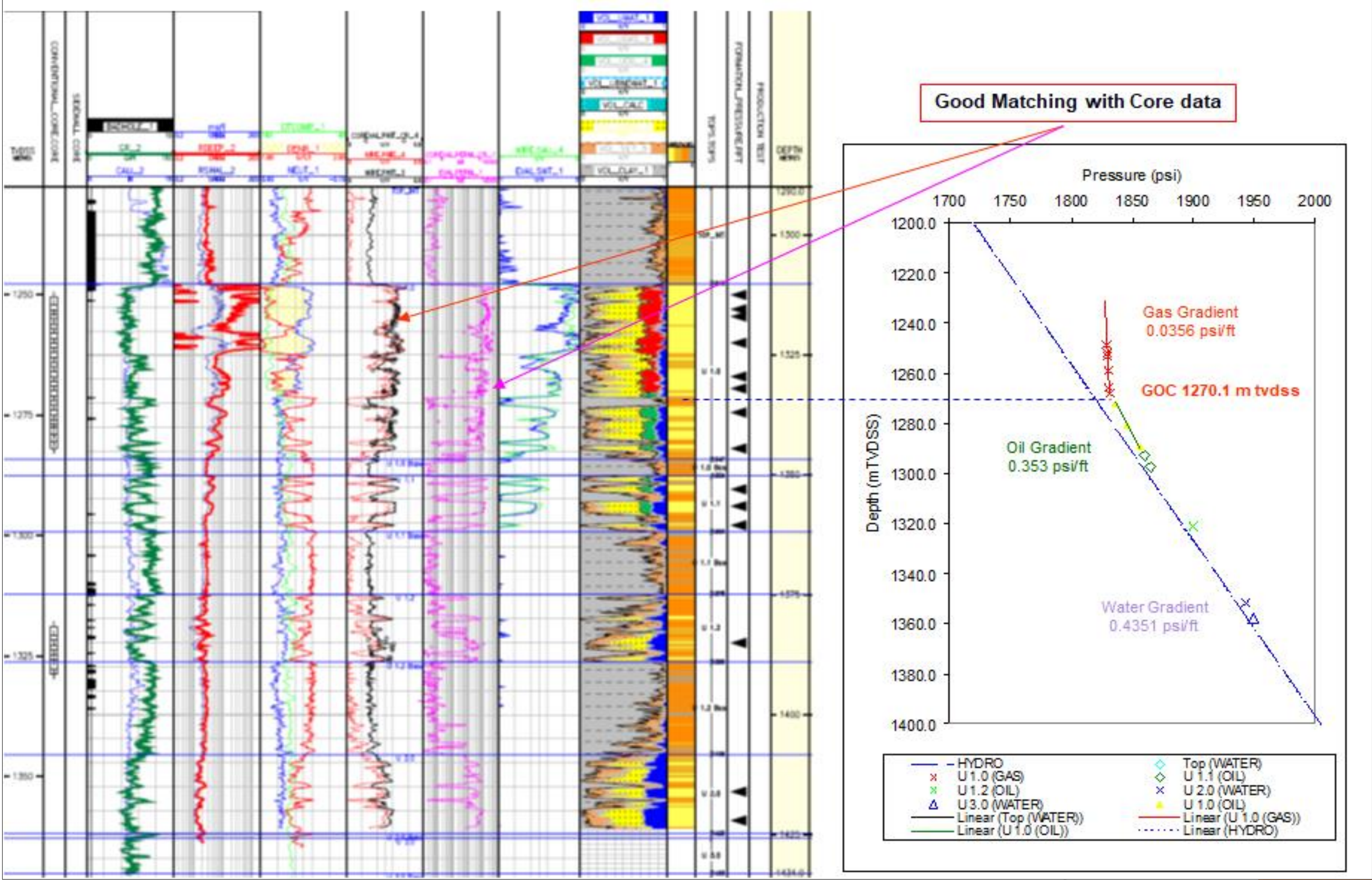


Good Core-Logs Porosity comparison

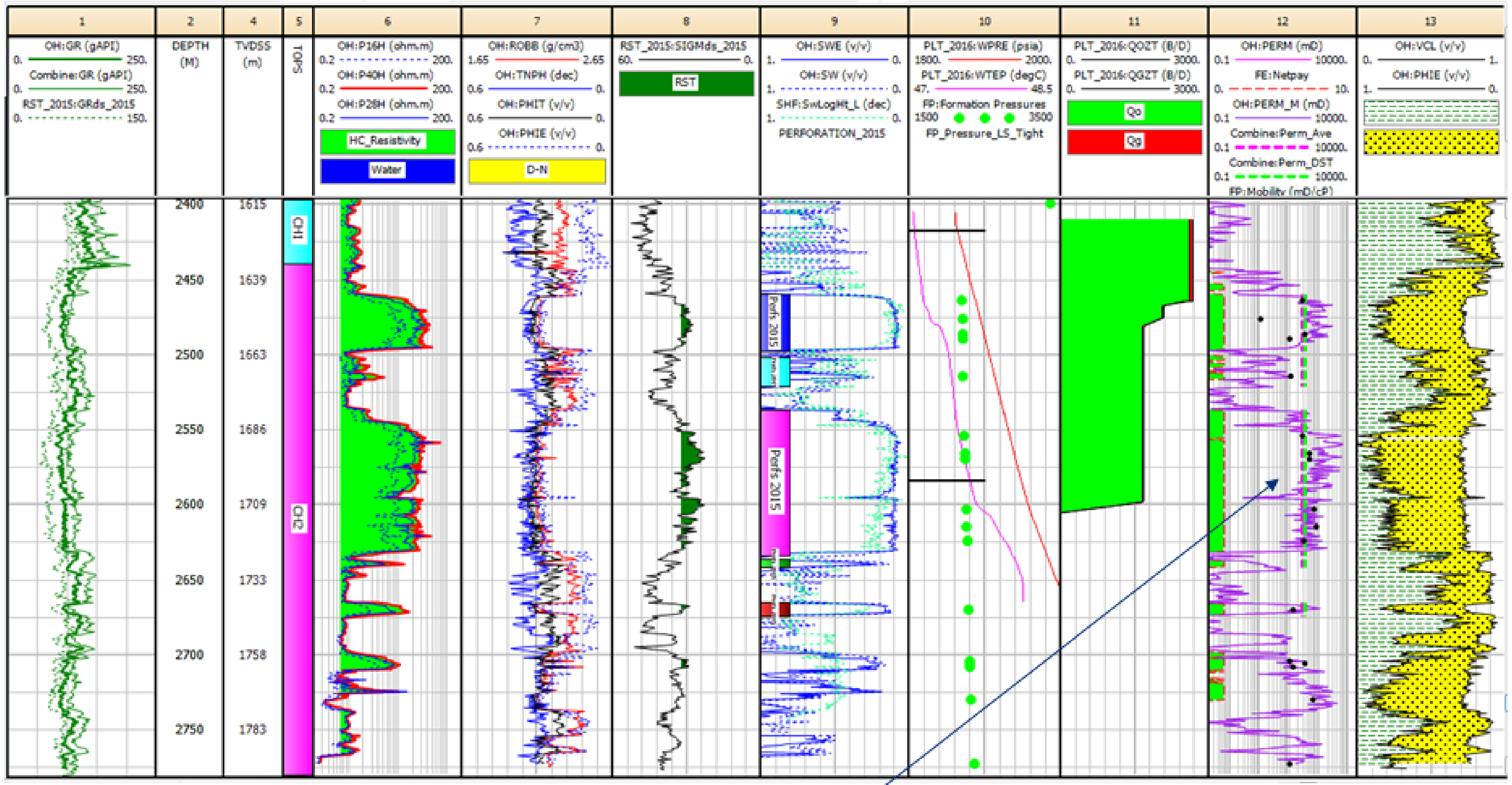
Good Core-Logs Permeability comparison

Good SHF and SW comparison

Well logs, Core, Formation Pressure & Fluid Sampling

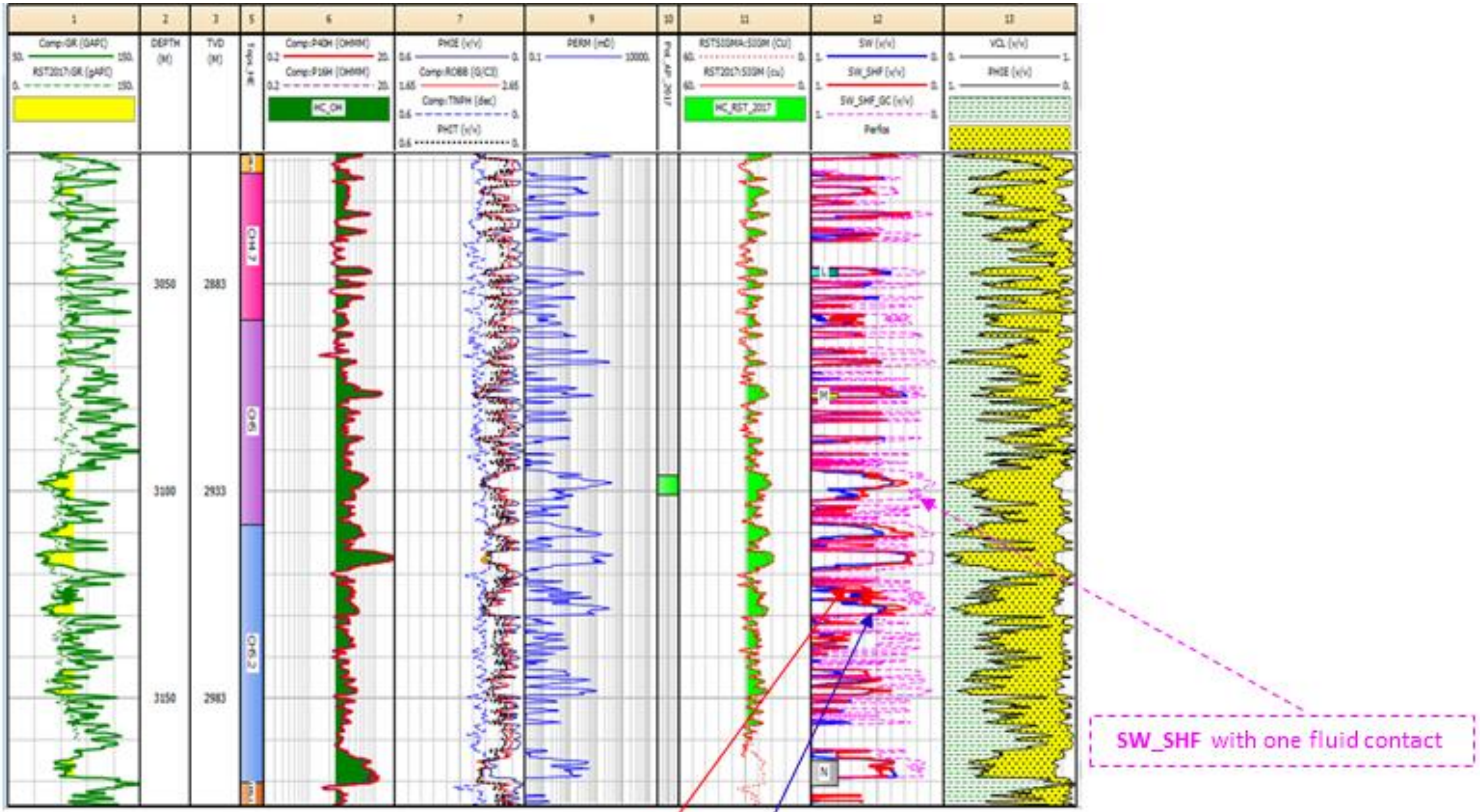


Well logs and Well Test Data



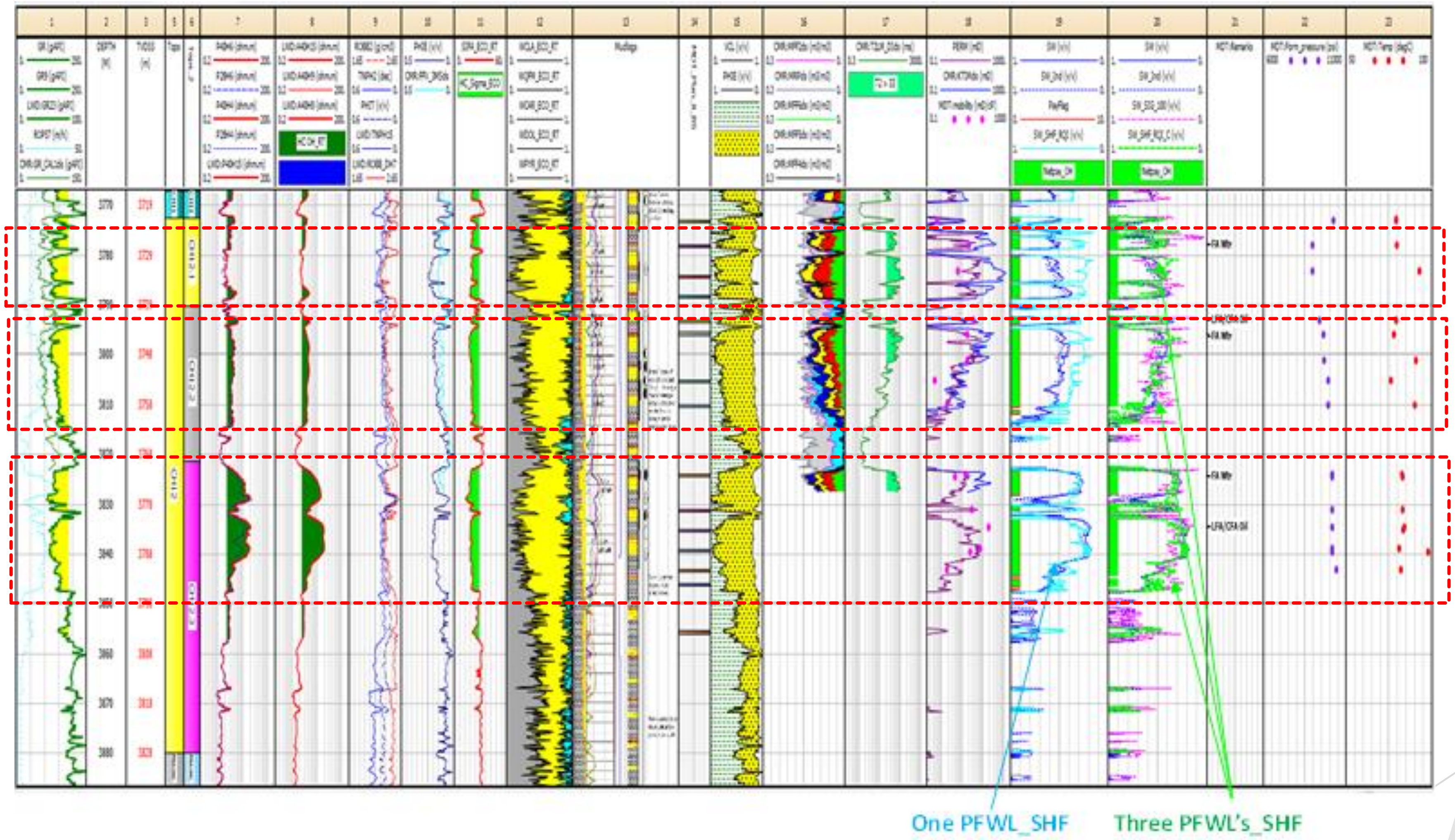
Good Ave Perm_Log (141mD) and Perm_DST(176mD) comparison

Important to Apply Correct Fluid Contacts for Saturation Height Model



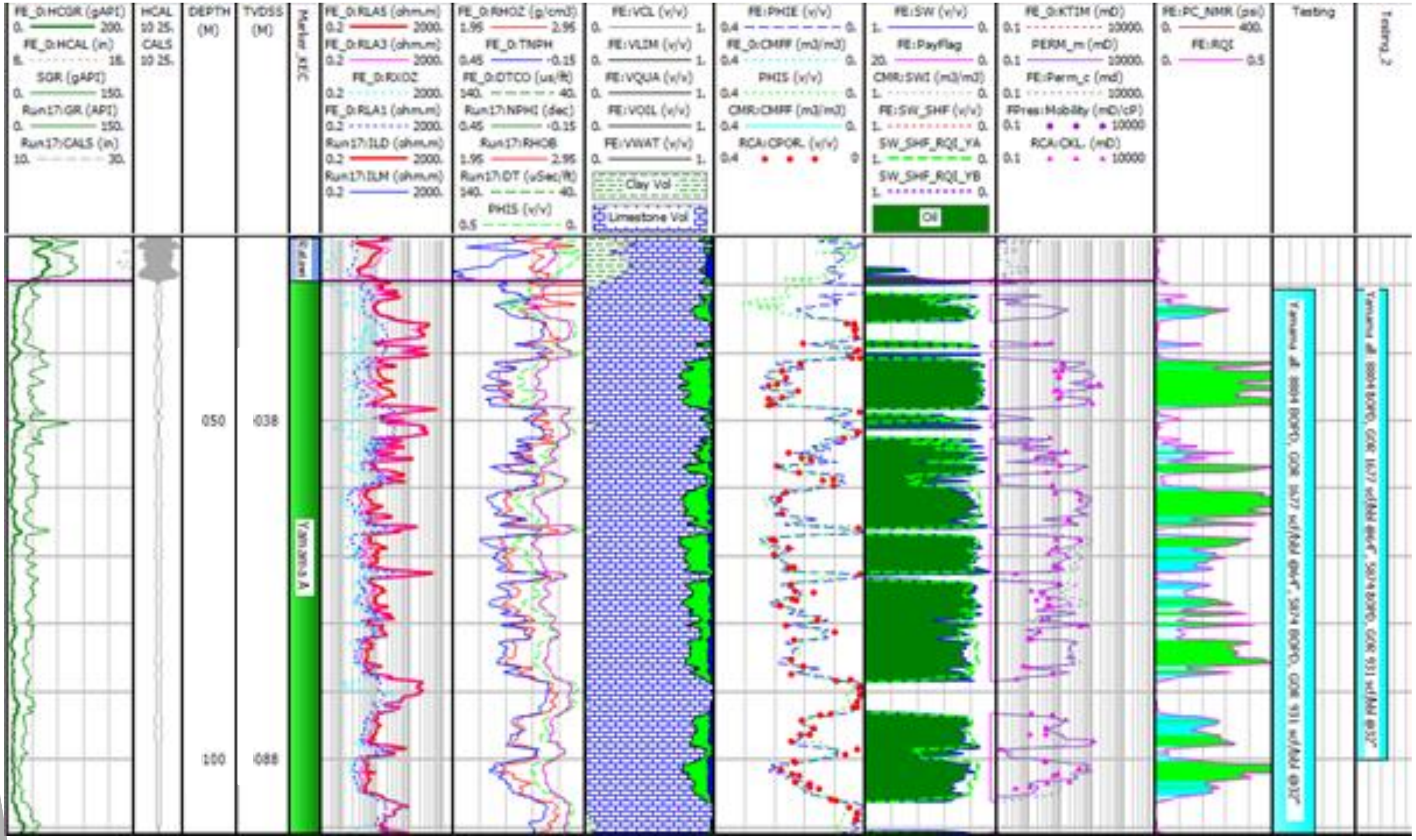
Contacts (PFWL) for every subunits provide better matching **SHF** with **SW**_resistivity compared to one oil water contact (PFWL).
It is important to apply different oil water contact for subunits considering variation of formation pressure and water production during well production

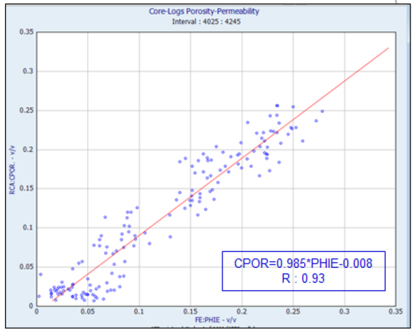
Saturation Height Model & SW Logs (Different Fluid Contacts)



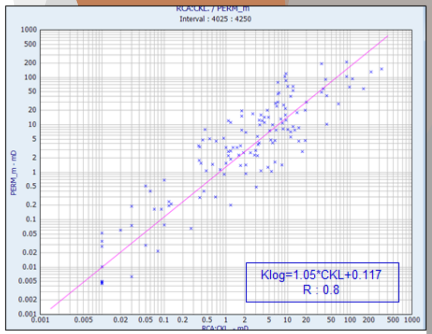
Water Saturation logs (Resistivity, NMR & Sigma) and SHF (one and three FWLs)

Porosity, Permeability, Saturation Height Model & SW Logs In Carbonate Reservoir



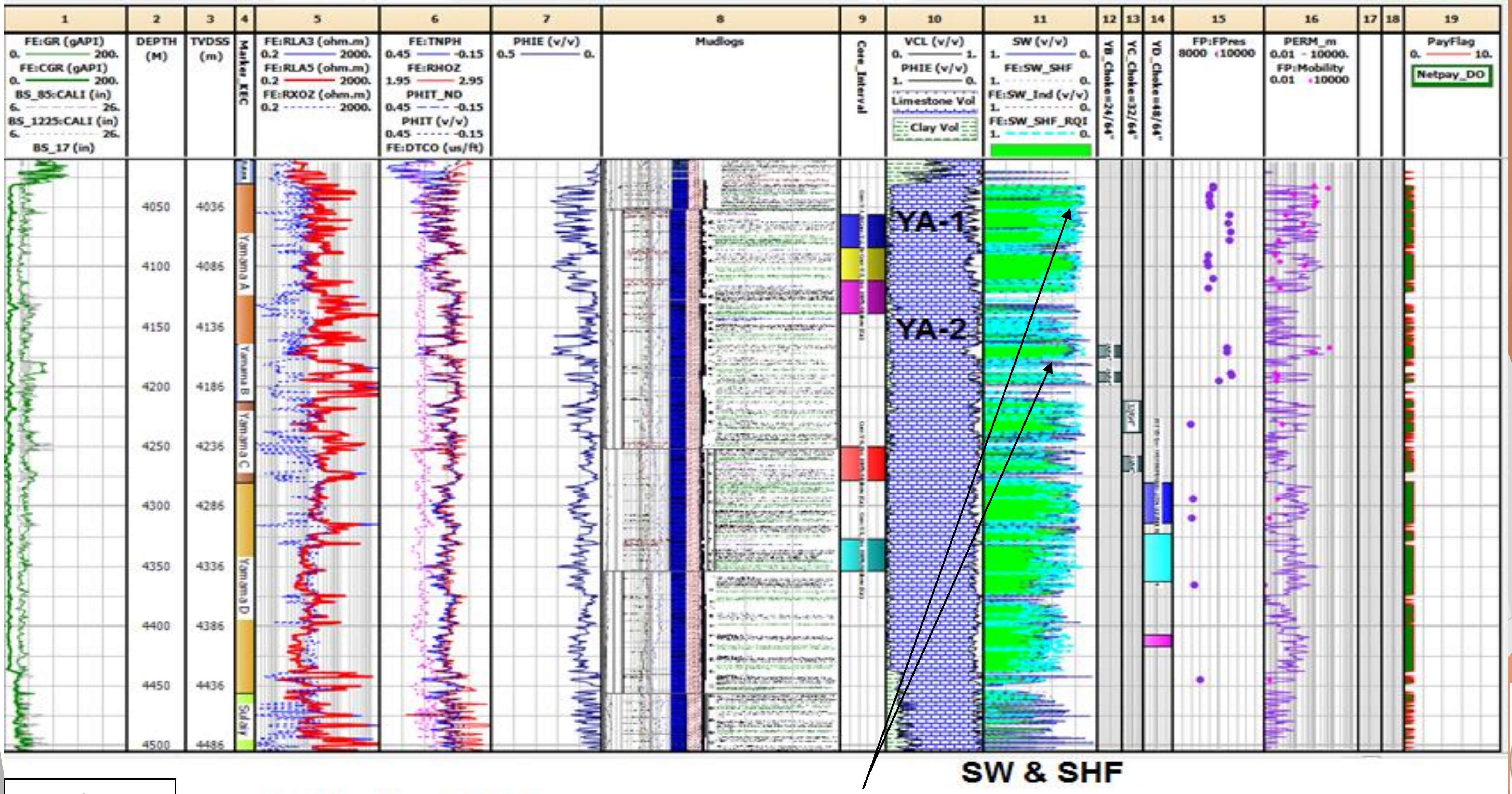


Good Core & Log Porosity Comparison



Good Core & Logs Permeability Comparison

Saturation Height Model & SW Logs in Carbonate Reservoir



CGR for VCL

PFWL: ~4470 m TVDSS

POWC_YA1_SHF: ~4250 m TVDSS

POWC_YA2_SHF: ~4350 m TVDSS

Good SW and SHF Logs comparison

PFWL: ~4500 m TVDSS

POWC_YB_SHF : ~4350 m TVDSS

POWC_YCD_SHF: ~4500 m TVDSS

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Conclusions

- The integrated petrophysical evaluation from logs, special core analysis (SCAL), geology, geophysics, reservoir rock typing (RRT), saturation height model (SHM) and detailed reservoir/fluid analysis are important to be used.

- The important to use core(SCAL)-logs calibration in the integrated petrophysical evaluation for reliable porosity, saturation, permeability, RRT and SHF, for reliable reservoir model.

- The different of water saturation resistivity with core saturation height model have been evaluated for an improving reservoir characterization.

- An initial water saturation, relative permeability and residual oil saturation from SCAL data have been used in evaluation. The sigma-pulse neutron capture and PLT are used to verify fluid contacts and water saturation changes during well production.

- The integrated reservoir evaluation approach has provided reliable assurance and important benefits for reservoir characterization and reservoir management of complex reservoirs.

Technical References

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- Muhammad A Gibrata, Lamia R, Yanfidra Y and S Ghedan, Advanced and Integrated Petrophysical Evaluation for Reservoir Characterization of Carbonate Reservoirs, SPE-198636.
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