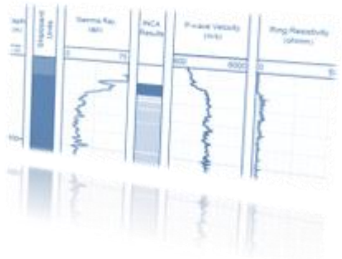
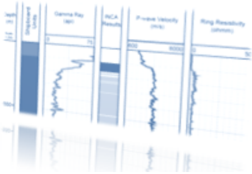


Petrophysics 101

Thursday 17th March 2016

The Geological Society, Burlington House, London

	Start time	End time	Name	Company	Talk Title
	09:00	***09:30***			***Registration***
	09:30	09:40	***Michael O'Keefe***	***LPS***	***Welcome & Introduction***
1	09:40	10:10	**Prof. Mike Lovell**	*Leicester University*	Fluid distribution in the reservoir: Porosity and water saturation, permeability, wettability & capillary pressure
2	10:10	10:35	**Iain Whyte**	*Tullow Oil*	Wellsite Petrophysics and raw data QC
3	10:35	11:00	**John Bennett**	*Bennett Petrophysics Ltd*	Integration of other data – Core, SWC, Pressures and Fluids
	11:00	***11:30***			***Break***
4	11:30	11:55	**Roddy Irwin**	*Gaffney, Cline & Associates*	**CLASTICS;** How to choose the right petrophysical evaluation method using standard logs
5	11:55	12:20	**Brian Moss**	*Independent Consultant*	**CARBONATES;** How to choose the right petrophysical evaluation method - Evaluation of mineralogy, pore geometry, saturation and permeability.
6	12:20	12:45	**Andrew Foulds**	*Petrafiz Limited*	**UNCONVENTIONALS;** How to choose the right petrophysical evaluation method - Lithology, Shale Volume and porosity
	12:45	***13:45***			***Lunch***
7	13:45	14:10	**Mike Millar**	*BG Group (Royal Dutch Shell plc)*	Water Saturation from Electric Logs
8	14:10	14:35	**Dr Peter Fitch**	*Imperial College London*	"Net & Pay" - The Petrophysicist's input to quantifying the reserves
9	14:35	15:00	**Dr Paul Basan**	*Reservoir Rocktyping (UK) Ltd*	NMR in petrophysics - Everything You Wanted to Know in 25 Minutes
	15:00	***15:30***			***Break***
10	15:30	15:55	**Barry Setterfield**	*Independent Consultant*	Core to Log integration and calibration
11	15:55	16:20	**Dr Joanne Tudge**	*Weatherford*	Permeability estimation and saturation height functions: A talk of two halves
	16:20	***16:30***	***Michael O'Keefe***	***LPS***	***Closing Comments***
16:30 onwards					***Refreshments***



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Important notice;

The statements and opinions expressed in this presentation are those of the author(s) and should not be construed as an official action or opinion of the London Petrophysical Society (LPS). While each author has taken reasonable care to present material accurately, they cannot be held responsible for any errors or omissions.

The aim of these presentations is to provide reasonable and balanced discourse on the titled subjects. Consequently it cannot consider in detail all possible scenarios likely to be encountered and caution is encouraged in apply these principles. Neither the LPS nor the authors can be held responsible for consequences arising from the application of the approaches detailed here.

The following pages contain the Abstracts

Petrophysics 101

Thursday 17th March 2016
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Petrophysical fundamentals: porosity & water saturation, permeability, wettability & capillary pressure
(or how to build the perfect sandcastle)
Mike Lovell, University of Leicester

This talk aims to define a simple range of basic petrophysical properties. ***Porosity*** is the potential storage space in the reservoir. In sandstones this may be interconnected space between cemented grains, while in carbonates porosity takes many complex forms; in unconventional reservoirs porosity may exist between inorganic minerals but can also develop in organic matter during maturation. We can define *total porosity* or, in a reservoir containing a significant proportion of clays, *effective porosity*, the pore space accessible to hydrocarbons. We typically estimate ***water saturation*** as a proportion of the pore space, and assume hydrocarbons fill the remaining pore space. In unconventional reservoirs (e.g. shale gas) this can be further complicated, or simplified, depending on where the hydrocarbons are located in the petrophysical model. ***Permeability*** concerns the ease with which a fluid flows and is based on Darcy's Law. As such it is not the flow rate, although proportional to it; permeability has dimensions of length squared. We can consider *single-phase or absolute permeability* with one fluid, or *effective permeability* when more than one phase is present; the ratio of *effective* to *absolute* defines the *relative permeability*. Permeability anisotropy can be important, while in unconventional reservoirs low permeability values make measurements problematic.

Most reservoir rocks are deposited in aqueous environments, and consequently start out at, or close to, 100% water saturation. It is through a process known as drainage that a reservoir becomes charged with hydrocarbon as the pore water drains. This movement and distribution of fluids is controlled by a number of parameters, including *wettability*, *capillary pressure*, and *buoyancy pressure*. These are determined by various factors including the chemistry of fluids and minerals, pore size, pore size distribution, surface roughness, and temperature and pressure. Distinguishing the free water level, determined by pressure measurements in a well or capillary measurements on core, from the hydrocarbon-water contact, determined by a change in water saturation to less than 100%, is critically important. ***Wettability*** describes the preference of a fluid to contact mineral surfaces, and depends on the relative strength of the intermolecular forces between the water/hydrocarbon and mineral grains. Sandstones are often water-wet while carbonates may have a tendency to be oil-wet; in shale gas reservoirs we often assume organic matter is hydrocarbon-wet while inorganic minerals are water-wet. ***Capillary forces*** are determined by the wettability contact angle, the pore radius, and the interfacial tension. In general a smaller pore size has a larger capillary pressure holding the water in place. For the water to drain and the reservoir to be charged, the buoyancy force must overcome this capillary force. Buoyancy depends on the density difference between pore water and hydrocarbon, and the hydrocarbon column height. Porosity & water saturation, permeability, wettability & capillary pressure; these are your essential petrophysical parameters, whether your aim is petrophysics, or simply a desire to build a better sandcastle.

Mike Lovell is Professor of Petrophysics at the University of Leicester, a University Distinguished Teaching Fellow, and a Senior Fellow of the Higher Education Academy. Mike's research includes both conventional and unconventional reservoirs; he also teaches classbased and field-based Petrophysics through Nautilus. Mike has been President, LPS; Vice President, SPWLA; President, SPWLA Foundation; Chair, Scientific Technology Panel for the Integrated Ocean Drilling Program; and Chair, University Geoscience UK.

Wellsite Petrophysics and raw data QC
Iain Whyte, Tullow Oil

While it may take only a few hours to acquire at wellsite, log data lives on for a very long time. A huge number of estimations and planning will be executed using this data and often the "customer" for the data will either not know how to quality control the data he/she is using or will simply have absolute faith that the data is of good quality.

The evaluations we perform on log data can only ever be of as good quality as the data itself. While it may be possible to redrive log with different calibrations etc, many errors causing bad data to be acquired are not recoverable after the event. As such it is mission critical that log data be properly quality controlled at time of acquisition.

The aim of this presentation is to share some experiences of poor data being acquired, how to identify this and what could be done to correct the situation.

Rubbish in, Rubbish out – Some notes to help turn electrical measurements into useable Petrophysical estimations.

Iain Whyte celebrates his 20th anniversary in the oil industry in 2016. He has worked for Tullow Oil for past 6 years in the role of Group Operations Petrophysics Lead supporting data acquisition of all types for Tullow Oil globally.

Prior to joining Tullow Iain worked as a Petrophysicist and Operations Petrophysicist for BP between 2004 and 2010 in locations including Turkey, Norway, Azerbaijan and Angola. Iain's background prior to moving to work for Operators was as a Wireline Logging Engineer, working 1 year for Weatherford and 7 years for Baker Hughes starting as a Cased Hole Engineer in 2006.

In his spare time he is the Past President of London Petrophysical Society and a rugby coach to London Scottish minis. He received his honours degree in Applied Physics from Robert Gordon University in 1995.

Integration of other data – Mudlog, Core, SWC, Pressures and Fluids
(or why Human Processed Interpretations are better than Computer Processed Interpretations)
John Bennett, Bennett Petrophysics Ltd

Petrophysics training often starts with a LAS file of "log data" from which a "Computer Processed Interpretation" delivers numerical estimates of reservoir quality and saturations.

In reality there are many other measurements and observations which can simplify and ground truth the analysis process, both reducing the workload and stress on the interpreter and significantly increase the confidence of other stakeholders.

This talk will summarise the high value information contained in the mud log, core descriptions, core analysis, formation tester and well test data.

Simple workflows and data visualisations focussing on data integration will be discussed, emphasising the importance of effectively communicating the results of high quality technical work.

John Bennett is a Formation & Fluids Evolutionist with more than 3 decades of practical experience spanning 4 continents.

CLASTICS;
How to choose the right petrophysical evaluation method using standard logs.
Roddy Irwin, Gaffney, Cline & Associates.

The petrophysical evaluation of sandstone reservoirs (clastics) can be regarded as “classical” petrophysics, since the interpretation routines and equations are well established in the industry. However, there remain pitfalls to be avoided: with the widespread use of multimineral probabilistic interpretation modules in modern petrophysical software it is all too easy to run a “black box” evaluation without due consideration to the reasons why specific algorithms or routines should be adopted or avoided. The risk is that an inappropriate evaluation could be performed without due consideration of the formation lithology, the porosity systems, the hydrocarbon phases and the available core analysis data.

The talk will cover the appropriate methods for the determination of lithology, porosity and water saturation in a variety of sandstone reservoir types using standard log data sets. The integration of the log evaluation with overburden-corrected core data is the key step in the delivery of a quality assured petrophysical interpretation. Ideally, the log interpretation will be performed on QC’ed and depth-matched log data; computations will be performed for the appropriate porosity system (Total Porosity vs Effective Porosity) and calibrated with core data. The water saturations should be calculated with the appropriate algorithms (clean sands vs shaly sands; saline formation waters vs fresh formation waters; massive sands vs laminated sands and shales) and compared to an independent saturation-height function derived from core and pressure data.

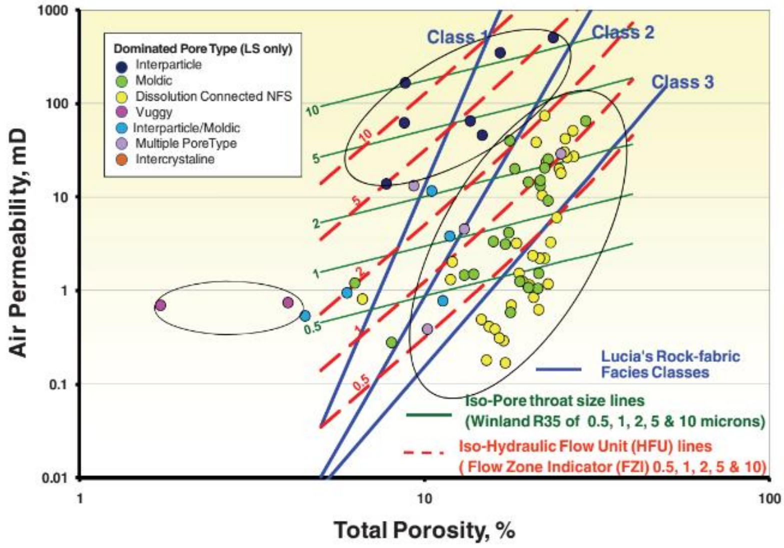
Petrophysics is applied problem solving and there is a certain satisfaction to be obtained when a petrophysical solution is achieved by the skilful integration of a variety of datasets. However, if the petrophysical evaluation is to be used for further volumetric or static/dynamic modelling, then the obligation still lies with the petrophysicist to communicate the uncertainties, ranges and inherent assumptions to the geologist and reservoir engineer.

Roddy Irwin: 25 years’ petrophysical evaluation experience gained during an international career with major oil companies and service companies. Currently, Senior Advisor in Petrophysics with Gaffney, Cline & Associates, UK.

CARBONATES;
How to choose the right petrophysical evaluation method - Evaluation of mineralogy, pore geometry, saturation and permeability.

Brian MOSS, Independent Consultant

The variable and often complex pore geometry present in carbonates requires that a thorough study of pore character is carried out in every case. Whilst it is true that some carbonates have predominantly interparticle porosity, most comprise a mixture of pore types that can include interparticle pores, intraparticle micropores, dissolution voids and fractures within the same formation. There may or may not be a lithological control on pore type. As a consequence, simple zonation schema based on lithology/mineralogy seldom capture completely the controlling heterogeneity, which exists from pore to reservoir scale, and a more thorough differentiation into distinct petrofacies is usually required. To this end, exploratory data analysis techniques and the use of advanced downhole technologies such as imaging, dielectric and magnetic resonance measurements, grounded in core inspection and analysis results, offer a robust workflow to derive the petrophysical deliverables required for the static reservoir model. The extent to which pore type differs in character from that of interparticle porosity will dictate the need for special measures for the evaluation of saturation for each petrofacies; one or more petrofacies present may be decidedly ‘non-Archie’ in their responses to log measurements and calibration against core and/or test data of saturation profiles derived from log data is frequently necessary.



The image, drawn from Bust et al 2011, illustrates a wide range in permeability for any given value of porosity, which is a characteristic of complex pore geometry. Several different possible partitioning strategies are shown relative to the pore types; none captures pore type variation in this example completely and therefore the most fit-for-purpose schema in any given reservoir may vary from reservoir to reservoir.

The image is of data from Ragland 2002, but is drawn from Bust et al., SPE 142819, 2011, SPE Reservoir Evaluation and Engineering. (Full citation in presentation.)

Brian MOSS. *Retired*. 25+ years petrophysical analysis and training experience and 10+ years software development and sales experience. (Worked in Government, in a large consultancy house, as an individual consultant, in a small software company and in a large service company; all preceded by a stint offshore in mud-logging.)

Water Saturation from Electric Logs
Mike Millar, BG Group (Royal Dutch Shell plc)

One of the primary objectives of Petrophysics is to provide inputs to the Hydrocarbons in-place equation;

$$STOOIP = (GRV * N{:}G * \Phi * (1-Sw)) / Bo$$

where ; *STOOIP = Stock Tank Oil Originally in Place*
GRV = Gross Rock Volume;
N:G = Net to Gross ratio
Φ = porosity;
1 - Sw = pore space filled with hydrocarbon
Bo = Formation Volume Factor
There is a similar equation for Gas in-place

Petrophysics plays the major part in providing net-to-gross, porosity and water saturation inputs. Water saturation (Sw) is the proportion of the rock void space (porosity) that is filled with water, and the assumption is made that hydrocarbon saturation is 1 - Sw. Water saturation can generally be determined with accuracy from electric logs and core, provided the appropriate techniques and evaluation parameters are used.

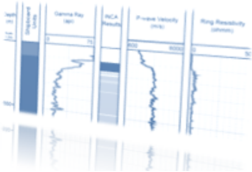
Sediments in the subsurface are generally assumed to be water bearing, and during hydrocarbon migration, some of this water is displaced by oil or gas due to buoyancy effects and trapping mechanisms. Capillarity will help determine just how much water is replaced by hydrocarbons. Formation resistivity logs are frequently used to determine Sw, as there is a distinct contrast between sediments containing conductive salty formation water alone, and those containing a mixture of conductive formation water and non-conductive hydrocarbons. Using two empirical equations, Archie (1942) was able to quantify this contrast, and these form the basis for most of the Sw evaluations done today.

As electric logs are frequently the only safe and cost effective way of collecting accurate borehole data across the entire reservoir interval, the focus of this talk will be on techniques for calculating Sw from logs, however some mention will be made of determining Sw from core.

We will show how to use the Archie equations and indicate some to the circumstances where they don't work and what might be done in their place. Mention will also be made of other logging techniques which give insight into water saturation

- Archie, G.E. (1942). "The electrical resistivity log as an aid in determining some reservoir characteristics". Petroleum Transactions of AIME 146: 54–62.
- Doveton, John H., 2001, "All Models are Wrong, but Some Models are Useful: "Solving" the Simandoux Equation." From Session J of the International Association for Mathematical Geology Conference, 2001, Cancun, Mexico.
- Waxman, M.H., and Smits, L.J.M.,1968, Electrical conductivities in oil-bearing shaly sands: Society of Petroleum Engineers Journal, v. 8, p. 107-122.
- Worthington, P. F. (2000), Recognition and evaluation of low-resistivity pay, Petroleum Geoscience, 6, 77-92.

Useful links; http://petrowiki.org/PetroWiki
http://imis.spwla.org/ - then Technical - Glossaryhttp://www.glossary.oilfield.slb.com/



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"Net & Pay" – The Petrophysicist's input to quantifying the reserves

Dr Peter Fitch, Imperial College London

According to the SPE, "reserves" represent the commercially recoverable proportion of a resource, justified for development and production. If a hydrocarbon resource is defined as the Stock-Tank-Oil-Initially-In-Place (STOIIP) then the reserves are calculated by applying a recovery factor. The recovery factor might be defined from analogue fields, special core analysis, analytical or numerical simulation methods. STOIIP is a function of the gross rock volume, ratio of reservoir to non reservoir within that volume, the porosity and oil saturation of the reservoir material, and the change in volume of a fluid when recovered to the surface from subsurface conditions. The concepts of 'net' and 'pay' are central within the calculation of STOIIP. Although definitions of both parameters can vary between disciplines, companies, asset teams and individuals we are slowly moving toward a more universally applied language.
In this talk we will discuss the various definitions of net and pay within the context of a conventional hydrocarbon reservoir before examining the approaches used to when a rock is quantified as being 'net' and 'pay' from petrophysical data. We will end by qualitatively applying these concepts to a real life dataset in the form of the LPS Training Dataset (a Jurassic Sandstone in the North Sea).

Please take a moment to visit **www.govote.at** and enter code **78 37 09** to answer three questions relating to your understanding of net and pay based on your experience to date. This is anonymous and results will be displayed during the presentation.

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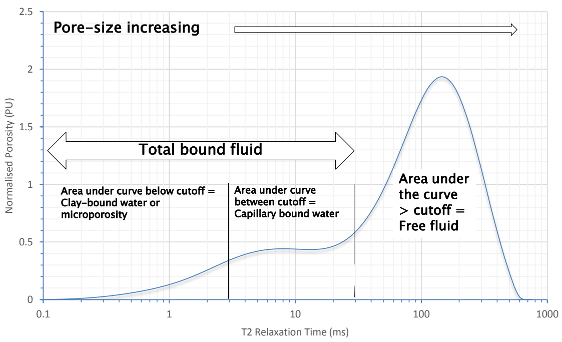
Everything you Wanted to Know about NMR in 25 Minutes
Dr Paul Basan, Reservoir Rocktyping (UK) Ltd

Nuclear Physics seems a complicated subject, and it is if you go into detail. Most of us, however, only want to understand enough to use the applications. My objective is to provide an overview and to build foundation in NMR petrophysics-albeit small-in 25 minutes.

The NMR petrophysical process follows a sequence that first polarises –aligns- hydrogen molecules to the magnetic field imposed by the tool, flips the magnetic field 900 and, using a radio-frequency coil, causes molecules to spin until they lose phase and realign. The acquisition process is controlled by the time for molecules to align to the magnetic field (T1 relaxation) and the time it takes for molecules to lose phase (T2 relaxation).
All NMR tools are a nonradioactive source for obtaining total porosity and a spectrum for showing how porosity and fluid is distributed to different parts of the pore system. The interpreted products from the spectrum are clay-bound water volume (or microporosity), capillary-bound water volume, effective porosity and free-fluid volume (see figure). Additional information about reservoir properties is available using the data as a proxy for pore size to estimate permeability and to determine irreducible water saturation. NMR data also provides a way to predict rock types based on pore geometry.



Forward model assumes system is water-wet and distribution = pore size. Assumes all water bound in small pores is immobile at a give Pc.

Both laboratory and field tools operate at low frequency, around 2MHz. Laboratory instruments acquire data from a 1.5” by 2” core plug. The coil surrounds the sample, which remains motionless inside the magnet. Logging tools record data from a sample residing outside the magnet and from a volume that varies according to tool design (i.e. log NMR inside-out compared to lab NMR). The physics of the lab and field instruments are similar but with enough differences to complicate direct application for validating (calibrating) the field response.

NMR tools record data from the near-wellbore region; deepest DOI is 4-inches, which means NMR investigates the flushed zone; fluid-typing depends on residual saturation. Logging tools come in different configurations, with some having a homogeneous, magnetic field and some gradient, magnetic field. Homogeneous-field tools are for formation evaluation whereas gradient-field tools provide both formation evaluation and fluid typing.

The “non-Archie” attributes of NMR make an ideal tool where Archie fails to provide a clear interpretation. For example, NMR often resolves interpretation issues in low contrast/low-resistivity reservoirs (shaly sands, thin beds and silt reservoirs). Other applications include situations where it is difficult to resolve complex lithologies from conventional tools (e.g. volcanoclastics, complex carbonates) and identifying fluid types.

Want to learn more about NMR, then visit: http://www.esandaengineering.com/Esanda-training-courses/course-schedule.html and find out about the London NMR Petrophysics course scheduled for 9th to 13th May 2016.

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Core to Log Integration and Correlation - the 'elastic' properties of rocks?
Barry Setterfield, Independent Consultant

Measurements derived from core material are taken as definitive because they have been measured under laboratory conditions on rock samples derived from the reservoir. Log measurements are seen as having greater uncertainty in consequence of the tools, means and environment by which they are acquired. Industry has long sought to reconcile log derived measurements with those derived from cores. The subject is fraught with assumptions and uncertainty. Firstly, there is depth matching the core and samples to the logs, secondly, there is the process of integration of the two measurements. A review of the basic principles and techniques will be presented, along with some of the uncertainties, assumptions and errors.

Barry Setterfield has over thirty eight years' experience in the international oil and gas industry, through practical experience in mudlogging, wellsite geology, exploration geology, operations and petrophysics. He has worked either as an employee or consultant for the following companies to name but a few: Core Laboratories, Amoco Production Company, Amerada Hess, Total, BP, Shell and BG in the UK, Central and South America, West Africa, North Africa, Arabian Gulf and SE Asia. He was trained in petrophysics at Amoco's Research Centre in Tulsa, Oklahoma in the mid 1980s.

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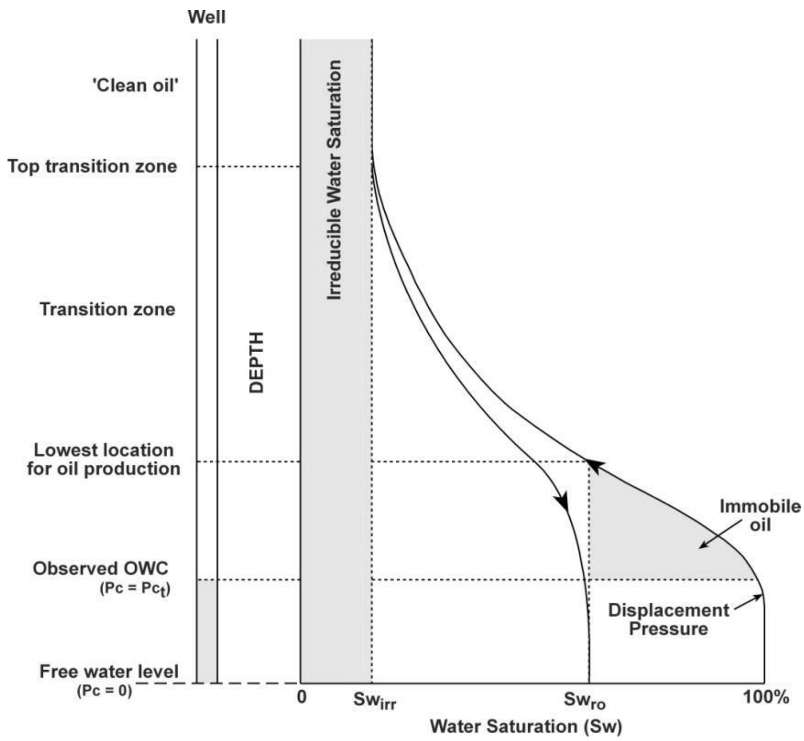
Permeability estimation and saturation height functions: A talk of two halves

Dr Joanne Tudge, Weatherford

Permeability, “the ease with which fluids can flow”, is possibly one of the most important petrophysical characteristics, yet one of the more difficult properties to estimate. Without a solid understanding of the permeability of a reservoir, the amount of porosity and hydrocarbon saturation is almost (but not quite!) irrelevant. Permeability is what allows us to extract the hydrocarbons from our porous reservoir.

Closely linked to permeability are capillary pressure measurements, and through them saturation height functions, which allow us to estimate the water saturation at a point above the free water level (FWL) based on capillary pressure.



In this talk, we will briefly introduce saturation height functions, what they are and how we can use them, we will also explore some of the different ways to estimate permeability and how it links to saturation height functions.