Petrophysics 101:
Core Analysis Essentials

Thursday 16th March 2017
The Geological Society, Burlington House, London

	Start time	End time	Name	Affiliation	Talk Title
	09:00	*09:30*	*Registration*		
	09:30	09:45	*Michael O'Keefe*	*LPS*	*Welcome & Introduction*
1	09:45	10:15	*Tim Pritchard*	*Uni. of Leicester*	Core Analysis: Begin with an end in mind
2	10:15	10:40	*Stefano Pruno*	*Weatherford Labs*	Recent Developments in Core Analysis
3	10:40	11:05	*Jules Reed*	*Lloyd's Register / SCA*	Core Analysis: Getting it right
	11:05	11:35	Break		
4	11:35	12:00	*John Owens*	*Maersk*	Coring, handling & analysis: securing the value chain through a structured approach
5	12:00	12:25	*Craig Lindsay*	*Core Specialist Services*	"Not all permeability's are equal?"
6	12:25	12:50	*Alan Johnson*	*IPS Ltd.*	Integrated QC of Special Core Analysis: Waxman-Smits & Capillary Pressure
	12:50	13:50	Lunch		
7	13:50	14:15	*Mike Millar*	*Ind.*	A Case Study in Using Core Analysis to Optimise an Oil Field Development.
8	14:15	14:40	*Andrew Foulds*	*Petrafiz Ltd.*	Core Analysis for unconventional reservoirs
9	14:40	15:05	*Quentin Fisher*	*Uni. Of Leeds*	Petrophysical properties of tight gas sandstones: core and cuttings analysis
	15:05	15:35	*Break*		
10	15:35	16:00	*Richard Arnold*	*Corex*	Formation Damage: Trials & tribulations
11	16:00	16:25	*Jenny Omma*	*Rocktype*	Digital Core Analysis
12	16:25	16:50	*Marsha Maraj*	*Southbank Uni.*	An independent means of determining pore size distributions using NMR diffusion & T2 experiments
	16:50	17:00	Michael O'Keefe	LPS	Closing Comments
17:00 onwards			*Refreshments*		

Core

Analysis

Essentials

LPS

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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

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Core Analysis: Begin with an end in mind

Tim Pritchard, University of Leicester

Acquiring, analysing and integrating core analysis data with other field information to develop a good understanding of a field is a complex challenge, with a lot of practical choices to be made. Not infrequently, good technical work can be undermined as a result of poor choices that can be made at the planning, core acquisition,, stabilisation and transportation, sampling, cleaning and drying, and measurement stages. In turn these can adversely impact on the suitability of the data. In addition, when it comes to making some of these choices there can be significant controversy amongst petrophysicists regarding which option is best. This presentation highlights some of the options faced at different stages when seeking to design a programme of core analysis work, and explores the different questions and arguments that should be considered when determining the best way forward.

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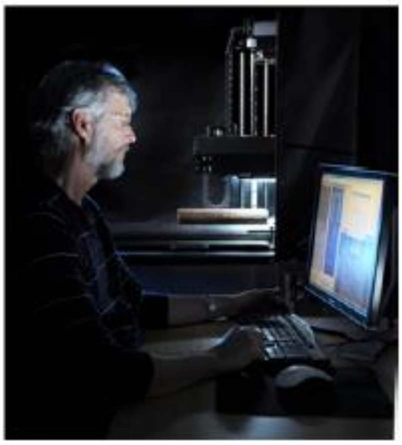
Recent developments in core analysis

Stefano Pruno, Weatherford Labs.



"Core samples truly represent the ground truth in the search for oil and gas. There are other established sets of integrated parameters such as fluid properties, well data, etc…, but unlocking the secrets of the rock will enable the operator understand the production potential of a reservoir and map out the best well construction scenarios for optimal field production."

Are these only nice words from a core analysis marketing brochure or can we really get more from the core? Since coring operations and core analysis is expensive and time consuming how can we justify investing in a full core analysis program and maximise the value of core analysis data. Why it is so important to define targets and deliverables for a successful core analysis program?

This LPS lecture will be focused on the recent developments in core analysis, the eternal quest for quality data to accurately define reservoir estimates and improve reservoir modelling.

We will also try to address the more relevant and interesting improvements in the core analysis field.

About the presenter

Stefano Pruno

Weatherford Laboratories Regional Technical Advisor for Core Analysis for Europe and African Region. He has a University background in Geology and Petrophysics (MSc), working in Conventional/Special Core Analysis field for the O&G Industry for approx. 20 years, with Weatherford Laboratories (Norway) for the last 10 years.

Core Analysis: Getting it right

Jules Reed, Lloyd's Register and SCA

Core analysis data results always merely are an interpretation of the measurements made. No reported data are direct measurement results. For instance, porosity is not measured – it is the ratio of two separate measurements and can vary dependent upon which measurement method is used; permeability is not measured but is calculated from several measurements (length, diameter, viscosity, differential pressure, and flow rate), etc. In order to correctly quality assure and quality control core analysis data, it is essential to understand the potential uncertainties introduced by varying processes, procedures and measurement errors. This presentation introduces many of the potential grounds for data uncertainty. Knowledge of the uncertainties is the first step in understanding the uncertainties leading to reduction of uncertainty and a more accurate dataset.

Coring, handling and analysis:

Securing the value chain through a structured approach

John Owens – Maersk Oil UK Limited

Successfully delivering well information objectives can be achieved through a robustly planned formation evaluation programme by applying the principles of a project maturation process. A pragmatic approach has been developed that compliments many existing corporate project planning systems which adopt a front end loaded philosophy.

The goal is to deliver maximum value in a safe manner through a structured four stage iterative approach - Planning, Execution, Application and Learning cycle (PEAL). It addresses the inherent challenges in designing a safe and fit-for-purpose formation evaluation project. The scope is intended to cover a holistic approach to fulfilling the well or overall project information objectives. As such the approach is generic and adaptable to the specific requirements of any reservoir setting and geographical location.

Project management principles of a coring, core handling and core analysis project are demonstrated using an extreme HPHT case history. From the project initiation, focus was placed on the entire value chain from setting the initial information objectives, the subsequent planning and execution through the deployment of tailored and specific solutions to subsurface descriptions required by end-users.

Fostering the extended team concept facilitated strong communications and the leveraging of niche skills which added significant value to the project. The key deliverables are safe wellsite operations whilst minimising chemical and mechanical damage to the core to obtain a representative, best in class core data set with a full audit trail and core master inventory. The project was tailored to harsh winter conditions at surface and extreme HPHT bottom hole conditions.

With high confidence in the results, the data was then applied to the static and dynamic models which are essential to future field development plans.

Essentials Core Analysis

LPS

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Integrated QC of Special Core Analysis: Waxman-Smits & Capillary Pressure

Alan Johnson, Integrated Petrophysical Solutions (IPS) Ltd

The Waxman Smits Relationship is quite well known:

$$\frac{1}{R_t} = \phi_t^{m*} S_{wt}^{n*} \left(\frac{1}{R_w} + \frac{BQ_V}{S_{wt}} \right),$$

The relationship was derived in the 1960s based on a series of detailed laboratory measurements on sandstone core samples containing various fractions of clay. Today, in reservoirs where shale effects are predicted to have a significant impact on electrical conductivity, it is a common practice to include the measurements required to derive the key Waxman Smits parameters: cation exchange capacity (Qv), m*, n*, in programmes of Special Core Analysis.

This presentation will review basic Waxman-Smits theory and discuss the estimation of Qv using the variable salinity (Co/Cw) technique, in particular the detailed QC of the individual measurements. The talk also highlights the importance of using brine of the correct salinity in the core analysis of shaly sands.

The presentation will go on the explain use of the 1979 Hill, Shirley and Kline bound water relationship to integrate the results of Qv, mercury-air and air-brine capillary pressures to quality control the consistency of the three independent sets of data. The presentation will close with a number of recommendations, based on the above, regarding the design of special core analysis programmes in shaly sand reservoirs.

"Not all permeability's are equal?"

Craig Lindsay, Core Specialist Services

Permeability, in the context of oil and gas, is the ability of fluids to move through the pore system in the reservoir and be produced into the wellbore. Along with porosity and saturation, permeability is one of the key deliverables of core analysis.

So it sounds simple but is it? There is Kg, Ka, K_{Klink}, Kw, Ko@Swi, Kw@Sor to name a few.

Permeability is a function of many factors including rock and fluid properties, saturation, overburden pressure & wettability.

In this presentation we look at the definition of permeability, how it is measured, how it is reported and why it is important to measure a permeability that is representative of the reservoir of interest.

Many assumptions are made about permeability – as consultants we often get asked why is Kw so low compared to Ka, why is Ko@Swi higher than Ka for example? The range in permeability measured on the same rock with different fluids and under different conditions can have a dramatic effect on the apparent ability of a fluid to flow. This can have significant positive or negative implications for the economic production of hydrocarbons. Either way, we need to understand what factors apply in each situation.

And then there is shale!

Permeability has many guises but core is of profound importance in enabling us to acquire the necessary data to make informed commercial decisions on all types of potential and actual hydrocarbon reservoirs.

Bio: Craig Montrose Lindsay

A geologist by background, Craig has 36 years of experience in the core analysis industry. After 18 years working in the lab in a wide variety of roles, Craig joined Helix RDS consultancy in 2002 and went on to found Core Specialist Services in 2010. Core Specialist Services are a consultancy specialising in the planning, design and management of core based studies. Craig served as President of the Society of Core Analysts from 2012-13. Core Specialist Services have a combined total of more than 120 years in the core analysis industry.

A Case Study in Using Core Analysis to Optimise an Oil Field Development

Mike Millar, Independent.

This case study concerns a small oil accumulation in the North Sea, producing from shallow marine sandstones. The oil is being produced through sub-sea completed wells, tied-back to a floating production vessel.

Conventional and special core analyses were integrated with log data to derive reservoir property inputs for the geological model which provided a range of in-place oil volumes. These were incorporated into the reservoir engineering model that provided reserves estimates that established the commercial potential of the field.

Core from the discovery and appraisal wells shows large variations in quality within the reservoir sandstone, which are strongly controlled by facies. A Production Log spinner survey on an exploration well test showed how these variations control productivity, thus an understanding of the facies distribution was essential in planning well positioning and completions strategy. A full facies study was undertaken on the available core and incorporated into a regional framework. The facies modelling was integrated with core analysis to better estimate permeability from logs.

The field development comprised high angle oil production wells and water injection wells. Well positioning and hole angles were chosen to maximise exposure to the highest permeability intervals. Real-time LWD logs, calibrated to core analysis results, were used to confirm each well had sufficient productivity potential prior to completing. Contingent side-tracks were included in the development plan.

Formation strength measurements on the core indicated that there was a high risk of sand production, which would be exacerbated by water breakthrough. Accordingly the wells were gravel packed to stabilise the sand face and prevent sand production. Sieve analysis was used to determine the size of gravel and sand screens to be used.

Core Analysis for unconventional reservoirs

Andrew Foulds, Petrafiz Ltd

Core analysis plays a fundamental role in the early evaluation of most unconventional reservoir types as well as conventional reservoirs. The key to successful reservoir management is a committed, cross discipline team, with a sense of long term stewardship and ownership, managing high quality accurate datasets. Formation Evaluation data, specifically core data, is used at every stage of a reservoirs life cycle, and poor quality data affects decision making, further increasing operational risk and ultimately effecting the overall strategy and profitability of any E&P company exploiting unconventional reservoirs.

This presentation primarily concentrates on the collection and evaluation of shale source rock (SSR) plays, but also briefly discuss some of the core related techniques that cross boundaries between shale source rock plays and coal bed methane (CBM) reservoirs. This presentation is only an introduction, and only touches on a subject that is somewhat in its infancy, and which is ever-evolving, both from a consistent technology perspective, but also from a methodology, accuracy and sample selection view point. A vast amount of university based research, as well as peer reviewed papers written, has been undertake on this subject in recent years; I believe it swamps all previous core analysis related research and subsequently published literature from when core analysis started in its modern form in the 1930's.

Cutting cores is an emotive subject, why? – It is hard to fathom… – but I am sure we can all guess the major bugbear. However, it must be remembered that core analysis forms a "cornerstone upon which formation evaluation rests" and the "benchmarks to obtain a calibration of the meaning of oil field data" (***Keelan DK, paper SPE4160, Nov 1972).*** Furthermore, core analysis forms the basis for many other extraction industries, which will core continuously and often, to solve geological and assessment related questions. Despite wireline logging methods becoming increasing sophisticated, core data is still essential to proper calibration of logs and this is especially so in unconventional reservoirs.

As with all core programs for any exploration, development or production wells, they should be designed to cost effectively gather core material to characterize all the major facies within the field at all stages of the appraisal, development and production cycles of any field development. It must be stressed that unconventional core analysis comes at a financial premium and costs can be generally considered high when you compare against conventional core analysis studies, therefore selective sampling programs are a must; conventional 1 ft sampling, at over $1000 per sample (depending on the gambit of tests) can soon escalate into a cost regime that is not going to do you any favours with Management.

Remember core material and subsequent analysis is for full field life – not just to characterize a well, in the short term. However most unconventional reservoirs have extensive core analysis programs, in the sense of numbers and the amount of core taken, in the very early stages, i.e. first few wells in a play, in an attempt to understand the play and effectively place subsequent production wells. As most of the subsequent drilling is through horizontal wells, later project life coring is not as common. AS an example a major US based core analysis laboratory told me that they hardly get any core from the old seven sisters of US shales plays (Eagle Ford, Haynesville, Marcellus, Bakken, Fayetteville, Barnett, Woodford) but were receive lots of cores from the in-flavor Permian Basin wells from the various shale and hybrid plays in this area.

Unconventional core analysis programs are primarily designed to collect early time data, not just from a typical petrophysical core to log calibration position and subsequent volumetric assessment viewpoint, but from an inorganic and organic geochemistry perspective as well as providing key information for the design of any future fracture stimulation through geomechanical and formation damage style measurements

It is critical to understand the benefits of core analysis and how to use the data from an unconventional perspective, but possibly more importantly understand the pitfalls and where not to rely on the core data alone; core analysis is not the panacea for all petrophysical problems.

Some of the key elements (KPI's) that make a successful shale source rock play – with core based elements coloured in Fuchsia.

Petrophysical properties of tight gas sandstones: core and cuttings analysis

Quentin Fisher, University of Leeds

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Large volumes of gas are contained within tight sandstone reservoirs but these are often only marginally economic to produce and reservoir characterization can be time consuming, difficult and expensive. There is also a general lack of high quality routine core and special core analysis data available from tight gas sandstones. A large JIP, PETGAS, was therefore established to generate a high quality database of the petrophysical properties of tight gas sandstone reservoirs and to create a fundamental understanding of the controls on these properties that can be used to improve the quality and speed of reservoir characterization but at reduced costs. Around 300 samples have undergone extensive sample characterization including porosity, gas permeability vs stress, brine permeability, electrical resistivity, NMR, ultrasonic velocity vs stress, Hg-injection analysis, BET, QXRD, XRF, as well as microstructural analysis using optical and secondary electron microscopy. Around a third of these have undergone special core analysis including air-brine capillary pressure, gas relative permeability, saturation index, pore volume compressibility and stressed Hg-injection analysis. These results have been incorporated into new data mining and visualization software, PETMiner, which improves QC and interpretation of the results.

Key results from this study will be discussed including:-

- The stress sensitivity of core analysis measurements (e.g. permeability, resistivity, MICP data) and their implications for core analysis and wire-line log interpretation.
- The time required for equilibrium to be reached for specific measurements (e.g. air-brine capillary pressure, electrical resistivity, brine permeability).
- Micro- and macro-structural controls on key properties.

Work will also be presented to show how key petrophysical properties of tight gas sandstones can be rapidly estimated from microstructural information obtained from both core and cuttings. Finally, the presentation will show how the results from the study can be used to make rapid estimates of likely flow rates from tight gas sandstone reservoirs.

Formation Damage: Trials & tribulations

Richard Arnold, Corex

Formation damage is described as changes to the reservoir that can impact upon well inflow. This area could be better understood as “Improved Hydrocarbon Recovery” as it presents opportunities to better understand reservoir behaviour, add value to decision-making, and reduce risk. The presentation will give an overview of some of the aspects of well operations that can cause issues, the types of mechanisms associated with them, how the use of reservoir-conditions studies and simulations is an essential tool, and give some examples of innovative interpretative techniques that have been developed in recent years.

COREX are the world leaders in Formation Damage analysis and have the biggest independent Formation Damage Laboratory facility, which is able to simulate the Formation Damage problems in specialized laboratories.

Richard Arnold is a core analyst with nearly 40 years industry experience gained working on a wide variety of formation evaluation and field development projects in most major oil provinces. Richard is a Past President of AFES and will be chairing this year’s DEVEX conference being held in Aberdeen in May.

Digital Core Analysis

Jenny Omma[1], Gavin Hunt[2], Richard Williams[2], Hanish Yadav[3]

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A good knowledge of the mineralogy, porosity and texture of reservoir and overburden rocks is an important aid to petrophysical log calibration and properties prediction. The study of core provides the best possible determination of rock characteristics. Digital core analysis techniques allow uniquely rich and nuanced datasets to be gathered from this valuable material and provide a step change in the detail of mineralogy, porosity and textural data that can be applied to the petrophysical workflow.

This talk will provide an overview of three currently available digital core analysis techniques:

1) Short wave infra-red spectroscopy, delivering continuous, digital sub-mm scale mineralogical, fluid and textural maps of entire slabbed core surfaces.

2) Automated scanning electron microscope analysis of 2D rock surfaces, delivering micron scale, digital mineralogy, elemental composition, porosity and textural datasets for representative rock types.

3) Micro-CT analysis of miniplugs, providing micron scale 3D digital representations of rocks, enabling digital flow properties modelling.

The talk will also present ongoing work to further automate these digital workflows, a requirement for creating truly **Big** datasets, and ongoing work to apply machine learning techniques to harness the power of these key datasets.

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An independent means of determining pore size distribution using NMR diffusion and T2 experiments

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The pore size distribution (PSD) of producing reservoirs strongly influences hydrocarbon recovery and fluid displacement. Mercury Injection Capillary Pressure (MICP) tests are commonly used within the petroleum industry to acquire PSDs. Nuclear Magnetic Resonance (NMR) also offers an alternate means to independently obtain PSDs through the combination of NMR diffusion and transverse relaxation time (T2) experiments. Diffusion experiments can provide the surface relaxivity of the material. This allows NMR T2 data to be directly correlated with pore size once an appropriate pore shape factor (surface area to volume ratio) is used.

The main purpose of this talk is to provide an introduction to the use of NMR experimentation as a stand-alone technique to derive PSDs. It outlines the specific methodology of converting NMR diffusion and T2 data into PSDs and compares the findings to conventional MICP results. The challenges and limitations of the NMR approach are then further explored which culminates in a discussion of selected techniques (including the use of micro-computed tomography) which can be used to make the approach more robust.

In this work, Berea sandstone samples were subjected to mercury injection capillary pressure (MICP) testing as well as NMR diffusion and T2 experiments. The surface relaxivity of these samples was found to be 27 µm/s. Assuming the pores to be spherical, PSDs were derived which ranged from 0 – 40 µm and had a mean pore radius of 8.7 µm. This compared well with the MICP results in which the mean pore radius was 6.1 µm. These results show that NMR experiments can provide an independent and realistic estimate of the PSD of reservoir media. This can reduce the time and cost normally associated with conventional core testing methods.

Keywords: NMR, T2, diffusion, pore size distribution.