Schlumberger Reservoir Laboratories

Know Your **Reservoir**

As the exploration and production of oil and gas moves into more-challenging environments, E&P companies face **more-complex reservoirs.**

Rock and fluid analysis performed at Schlumberger Reservoir Laboratories provides the information you need to address increased complexity and better understand your reservoir. This improved understanding can add to drilling and development effectiveness and efficient, enhanced production.

Today we're expanding and adapting our services to provide you with even more-comprehensive information. We know your success depends on more than just large amounts of data: It requires high-quality data and analysis that can actually deepen your understanding and enable better decision making.

Integrated Laboratory Services for Better Reservoir Understanding

Individual analysis of reservoir rocks and fluids provides unique perspectives on their respective properties and behaviors. We're committed to bringing you **additional insights through integrated rock and fluid analysis** for even better reservoir understanding.

To expand the potential of this integrated approach and bring you its benefits, we're adding services and capacity to our analysis capabilities. This includes colocating rock and fluid laboratories in "hubs" around the world, supported by local expertise; deployment of new technology; standardized operating procedures; quality control, quality assurance, and reporting processes; and the cross-training and development of our staff.

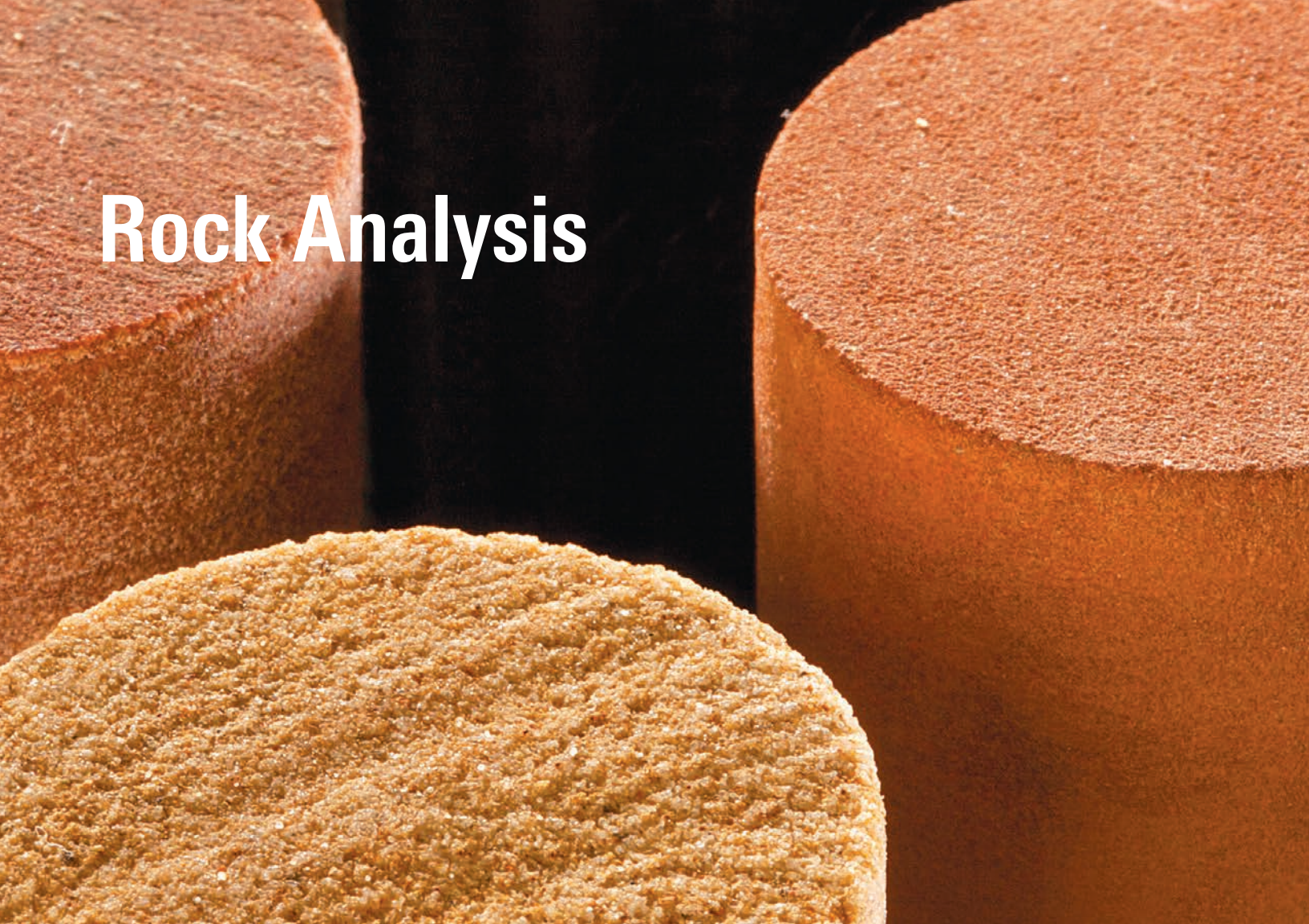
The result is a truly global reservoir characterization services organization, complete with industry-recognized expertise in reservoir, rocks, and fluid sampling and analysis. This proficiency is backed by our extensive research, development, and engineering capabilities.

Advantages of integrated laboratories and analysis

Our integration of rock and fluid laboratories and analysis capabilities provides a range of benefits.

- Dependable results: Standardized procedures and equipment support consistent delivery of reliable data.
- Reduced risks: The comprehensive information achieved from our full spectrum of rock and fluid analysis and expertise supports better decision making.
- Faster analysis: Expanded hub laboratory facilities require less shipping of samples to various laboratories.
- More meaningful results: Reports match and easily integrate with your own workflows.
- Trusted advice: Industry-recognized expertise and experience contribute to better outcomes.
- Simplicity: You'll benefit from one expert contact for all your rock and fluid analysis needs.

Rock Analysis



Building on the long experience and leadership of our **comprehensive TerraTek* rock mechanics and core analysis services** for both conventional and unconventional reservoirs, our global network of laboratories provides timely measurements that are fundamental in characterizing your reservoir.

Wellsite services

Our specialists process, catalog, preserve, and stabilize whole and sidewall cores at the wellsite to maintain their integrity during transport to our facility for laboratory testing. Core management ensures proper handling, identification, and storage in the laboratory. Services include canister desorption to measure evolved gas, content, and composition for reliable prediction of the gas in place.

Geomechanics services

Our geomechanics services lay the foundation for a complete understanding of the most effective stimulation treatments and the production potential of conventional and unconventional reservoirs.

Services include

- single- or multistage triaxial tests
- uniaxial strain tests
- thick-walled cylinder tests
- continuous strength measurements along the core length to assess heterogeneity (scratch testing)
- indentation tests.

These tests reveal a variety of geomechanical properties, including unconfined compressive strength, tensile strength, compressibility, fracture toughness, thermal properties, and complete shear failure envelope, including compactant cap and static and dynamic elastic moduli.

Routine core analysis

Measurement of basic properties helps you determine if a rock contains a fluid-filled space (porosity) and hydrocarbons in that space (saturation) and the ability of those hydrocarbon fluids to be produced (permeability). Core gamma logging links core depth to logging depth. Computed tomography (CT) scans indicate core heterogeneity.

Special core analysis

Detailed understanding of a reservoir requires additional measurements obtained through special core analysis (SCAL). Examples include

- calibrating electrical logging measurements of porosity and saturation
- determining a formation-specific cutoff value for the relaxation time from a nuclear magnetic resonance (NMR) log
- determining capillary pressure measurements to indicate pore throat distribution and evaluating saturation distribution as a function of height in the formation
- measuring the multiphase flow character of the formation
- evaluating wettability.

For tight shales and other challenging unconventional reservoirs, TerraTek TRA* tight rock analysis service provides a comprehensive representation of reservoir quality for the various rock classes in the core and a ranking of these from the best reservoir quality to the nonreservoir units. Reservoir quality is defined by hydrocarbon-filled porosity, permeability, organic content, degree of maturation, and pore pressure. Its assessment requires comprehensive TerraTek TRA service measurements of porosity, adsorbed gas, pore fluid saturations (water, oil, and gas), permeability, matrix mineralogy and microfabric, organic content, and organic maturation for each of the principal rock classes.

Formation damage testing

Tests evaluate return permeability after mud invasion, fluid-rock interactions, fluid-fluid interactions, and damage caused by pressure and temperature changes in the reservoir.

Petrology services

Key parameters to aid in the determination of reservoir quality (RQ) and completion quality (CQ) are obtained through detailed evaluation of rock texture and composition using core description, X-ray diffraction, Fourier transform infrared spectroscopy (FTIR), X-ray fluorescence (XRF), laser particle size analysis (LPSA), thin sections, and scanning electron microscopy (SEM). In our viewing room, your core can be examined in detail to help you understand the optimal way to develop and produce a field.

Source rock and shale screening

Our rapid infrared spectroscopy technique and isothermal adsorption and desorption measurements provide both mineralogy and total organic carbon (TOC) simultaneously on small samples of a formation. The method can also be used on cuttings from legacy wells to help you understand differences in productivity between existing wells.

Data integration petrophysics services

TerraTek HRA* heterogeneous rock analysis service is a workflow designed to improve the representation of core sampling in heterogeneous reservoirs and facilitate the integration of core, log, and seismic data. It is rooted on a foundational quantitative, unbiased classification of log data to determine zones of consistent or differing log response. The classification then facilitates the selection of samples for core testing up front and the integration of both quantitative and qualitative data across multiple disciplines (e.g., petrophysics, geomechanics, and petrology), and multiple scales (e.g., core, log, and seismic) when testing is complete. This leads to more accurate identification of target zones and the prospect for spreading knowledge across future wells using log data alone. It may also make possible extending this knowledge to regions that lack log data through upscaling and integration with seismic data.


Fluid Analysis

Our mercury-free laboratory services provide timely and accurate measurements and **expert interpretation of fluid phase behavior and fluid properties**—all essential for characterizing your reservoir. Areas of expertise include hydrocarbon fluid characterization for reservoir and production engineering applications. This incorporates reservoir fluid volumetric data (PVT), organic solid phase behavior characterization for flow assurance, enhanced oil recovery (EOR), aqueous and organic geochemistry, and analysis of trace elements, such as sulfur and mercury.

Wellsite sample acquisition

We have an unsurpassed record in successfully acquiring representative reservoir fluid samples in even the most challenging deepwater, HPHT, heavy oil, and hostile high-H_2S reservoirs. Our industry-leading downhole and surface sampling technologies combine with extensive sample management expertise to ensure the secure arrival of reservoir samples at the laboratory in the shortest time frame.

Sample restoration and validation

Our focused approach to sample quality and detailed workflows mean that only the most representative samples are analyzed to assure accurate and reliable data delivery. Integration with subsurface and surface data acquisition further supports quality control for the entire process, from sample acquisition to final laboratory analysis results.

Phase behavior studies

Our mercury-free phase behavior (PVT) systems analyze all fluid types, including challenging volatile and heavy oils, gas condensates, black oils, and waxy and asphaltenic fluids. In addition to the accurate, quality-controlled data, equation of state (EOS) modeling is available to support the calculation of in-place reserves and the design and optimization of production plans.

Reservoir fluid composition analysis

Accurate compositional data for reservoir modeling and design of processing facilities is one of the most critical sets of information generated from reservoir fluid analysis. We apply a full range of advanced gas chromatography and mass spectrometry techniques. Best-in-class calibration and data quality assurance and quality control processes also contribute to delivery of the most reliable data.

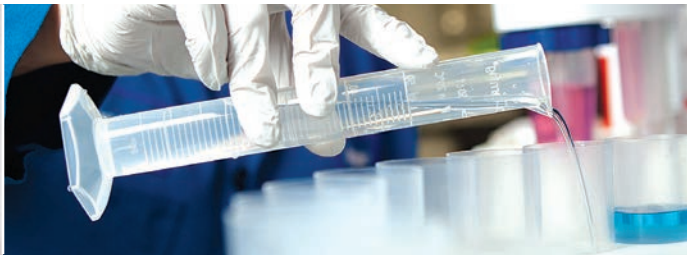
Flow assurance services

Industry-recognized domain expertise and laboratory services support flow assurance. Services include

- solids detection
- high-pressure microscopy
- rheology analysis
- live oil emulsion stability testing
- live and stock-tank oil viscosity measurements
- particle size analysis technology at pressure and temperature
- RealView* live-fluid organic solids deposition analysis for obtaining data for simulation and modeling of wax and asphaltene deposition in wellbores and pipelines.

Geochemical analysis

Geochemical fingerprinting using high-resolution gas chromatography for production back-allocation and compartmentalization studies is supported by best-in-class Malcom* interactive fluid characterization software and our global team of experts providing integrated interpretations of fluid datasets. Organic geochemistry studies for oil and source rock characterization incorporate a full suite of biomarkers and gas and liquid isotope analysis.



Water properties and analysis

We provide full water-sample acquisition and analysis services, supported by experts who advise on sample capture, preservation, shipping, and analytical methodologies. Services include routine and high-end analysis at our reservoir laboratories and performing measurements at the wellsite.

Wellsite chemistry services

State-of-the art services across our global operations help you meet challenges related to hydrogen sulfide and sulfur species and radionuclide and mercury characterization in reservoir samples at the wellsite.

Sample management

Adhering to strict global standards on sample and information security management—covering sample capture, unique bar code labeling, identification, dangerous goods transportation, regulatory compliance, tracking, analysis, storage, and disposal—provides you with confidence that your reservoir samples and analysis data are managed with the utmost care and attention.

Fluid Inclusion Technologies

Our unique **rapid analysis of trapped fluids and mineralogy** is applied to cuttings, whole or sidewall cores, and even outcrop samples to rapidly evaluate the entire borehole for the abundance, distribution, and composition of hydrocarbon species and aqueous fluids trapped in inclusions.

Fast, universal analysis

PetroFecta* automated trapped fluid and elemental composition analysis provides information in as little as 5 days for more than 500 cuttings samples and is applicable to any lithology or reservoir because fluid inclusions occur in all formations—conventional and unconventional.

Fluid inclusions in samples do not have a shelf life, because drilling fluids can only rarely cause contamination. No special sample preservation is required—which means that your archived cuttings or cores can be analyzed even many years after the drilling. Analysis requires only 1 g of sample.

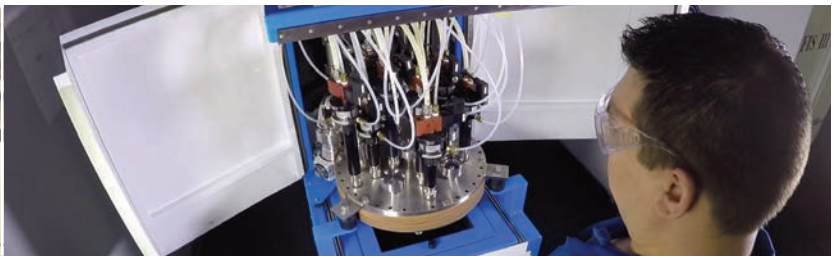
Three automated steps

The first step is RockEye* automated high-resolution photography in white light and ultraviolet (UV) light.

The second step, at the heart of analysis, is FIS* fluid inclusion stratigraphy analysis. After we capture the images, the sample tray is put in a vacuum chamber. The samples are crushed and we measure the volatile species released from the rock by using a highly sensitive direct quadrupole mass spectrometer. The process produces mass spectra from which selected species can be identified and plotted against depth.

The third step is elemental analysis by PDQ-XRF* automated X-ray fluorescence elemental analysis. We can analyze 35 elements, which are used to derive normative mineralogy.

Recently, we introduced diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS), which enables measuring the mineralogy directly and differentiating different type of clays.



Conventional and unconventional plays

For conventional reservoirs, fluid inclusion technologies answer questions related to active source rock, migration, paleo accumulations, seal effectiveness, proximity—or lack thereof—to charge, and timing of charge.

For unconventional reservoirs, fluid inclusion technologies can help identify the most productive vertical and horizontal penetrations, provide useful information for designing staged fracturing, and differentiate emerging resource plays and regional boundaries for prospectivity mapping.

Fluid inclusion petrography, microthermometry, and biomarker and gas isotope analysis

Screening with PetroFecta analysis identifies the most appropriate samples for more detailed investigation.

Fluid inclusion petrography is performed on thick, polished sections of rock material under transmitted plane-polarized light and episcopic illumination with a high-intensity UV source to provide

- microscopic examination of rock material for trapped hydrocarbons and aqueous fluids
- characterization of the distribution, abundance, and attributes of encapsulated fluids, such as fluorescence color
- partitioning of petroleum migration paths from paleo accumulations in conventional reservoirs
- maturity and effectiveness of local organic matter for petroleum generation in self-sourced unconventional reservoirs.

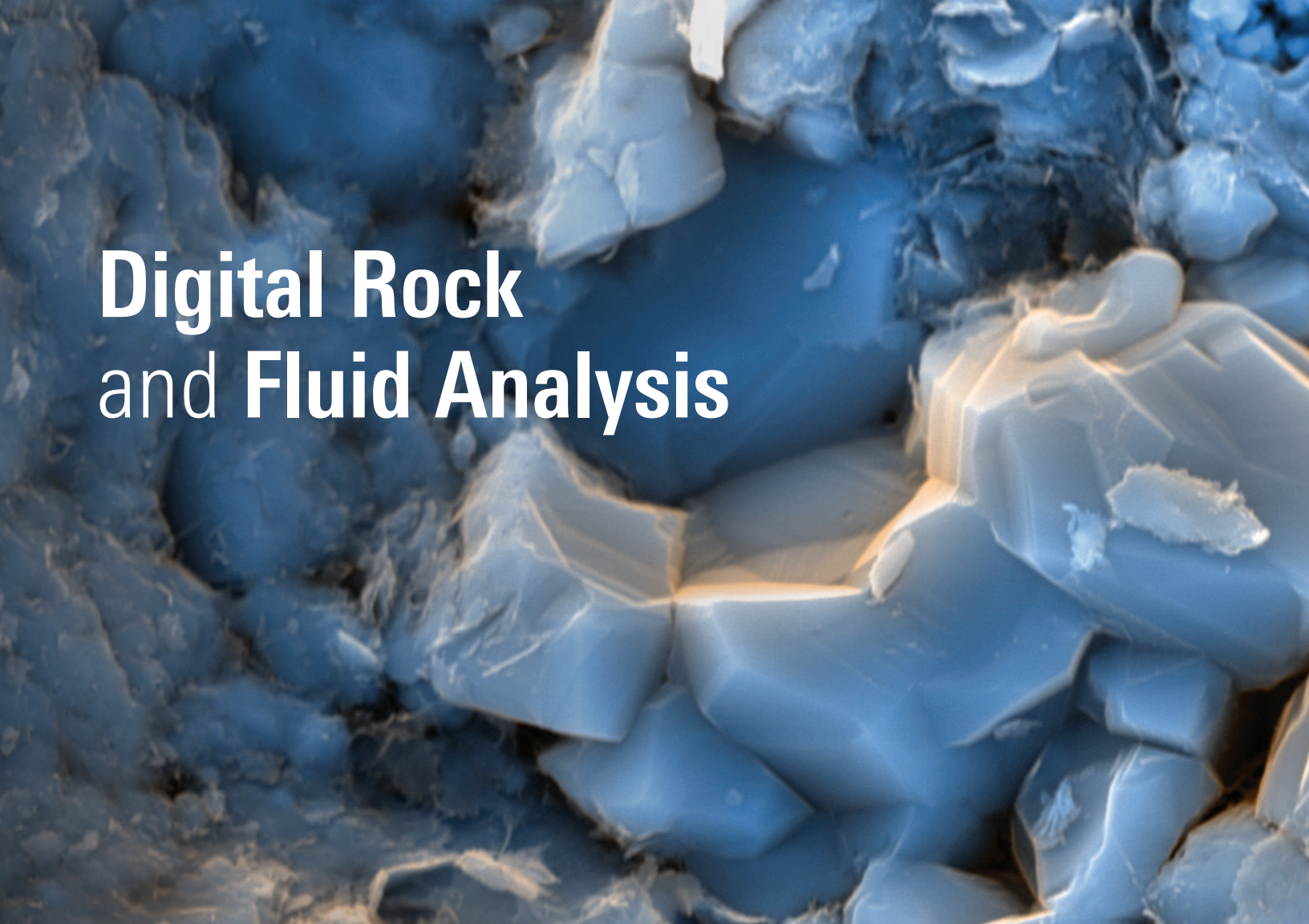
Advanced quantification of fluid inclusions applies microthermometry using a specially designed temperature-controlled chamber attached to a petrographic microscope. Phase changes and other observations within individual fluid inclusions are recorded and compared with appropriate phase diagrams or calibration curves to determine

- homogenization temperature of aqueous and petroleum inclusions
- proximity to bubblepoint or dewpoint at time of trapping
- determination of API gravity to within 2 API
- salinity of aqueous inclusions to infer fluid sources and evaluate the composition of irreducible water within reservoirs for calculating the water saturation.

Biomarker and gas isotope compositional analysis is performed by gas chromatography (GC) and by GC and mass spectrometry (GC-MS) along with determination of the $\delta^{13}C$ of fluid inclusions by isotope ratio MS (IRMS) for correlating data from rock material, hydrocarbon samples, and fluid inclusions.

Applications include

- correlation of shows and paleo accumulations to source rock
- maturity comparison
- biodegradation and thermal alteration assessment
- identification of potential end members for pay allocation.



Digital Rock and Fluid Analysis

Only CoreFlow* digital rock and fluid analytics services **integrate physical and digital rock and fluid analyses to create a 3D reservoir model** for rapidly simulating flow performance in all reservoir types under multiple production scenarios.

Physical and digital: All together like never before

CoreFlow services' all-in-one approach uses physical laboratory hydrodynamic and petrophysical measurements to refine pore-scale simulation data, which enables accurate measurement of relative permeability, capillary pressure, net present value, and other parameters that are vital to optimizing your reservoir engineering.

Digital rock

The digital rock component of CoreFlow services integrates high-resolution imaging that delivers a unique view into the pores with detailed direct pore-scale modeling. The digital rock models are built from whole-core CT scanning data, shadow projections of X-ray micro-CT scans, SEM, and focused ion beam SEM.

Digital fluids

CoreFlow services include the unique digital fluids element, which directly applies experimental fluid data in modeling to replicate the recovery processes occurring at the pore-scale level while accounting for reservoir conditions determined from your PVT data. The integrated laboratory measurements of fluid properties include viscosity, density, interfacial tension, composition, rheology, and phase behavior data.

Dynamic characterization

The dynamic combination of digital rock and fluid models is conducted in DHD* direct hydrodynamics pore flow simulation. This multiphase compositional hydrodynamic simulator is based on density functional hydrodynamics (DFH). DHD simulation has the ability to handle complex fluids, including surfactant and polymer solutions and phase transitions.

Optimized for high performance computing, DHD simulation is capable of performing multiphase modeling on digital rock models consisting of several billion cells. DFH method functionality includes multiscale modeling capability to scale up modeling performed on the higher-resolution models using lower-resolution rock imaging data. A nested multiscale approach is used to scale up high-resolution digital rock data to the size of the representative flow unit, which can be a plug or a whole-core section.

Accelerated digital experiments

CoreFlow services greatly accelerate conventional experimental laboratory workflows while bringing vital information about the pore-scale flow dynamics. Modeling results provide data that enable the calculation of static fluids distributions and dynamic flow performance to evaluate rock quality, wetting characteristics, heterogeneity, and the flow and distribution of fluids.

By conducting digital experiments, we optimize and complement the physical test workflow to achieve the final results faster and with higher confidence. Complex SCAL projects can now be performed in a few weeks, compared with years of laboratory studies. Digital EOR screening projects can compare EOR agents, conditions, and flooding sequences one to one, a task that is impossible to physically perform in the laboratory because the core samples cannot be reused after first experimental EOR coreflood.

Integrated Analysis in Action

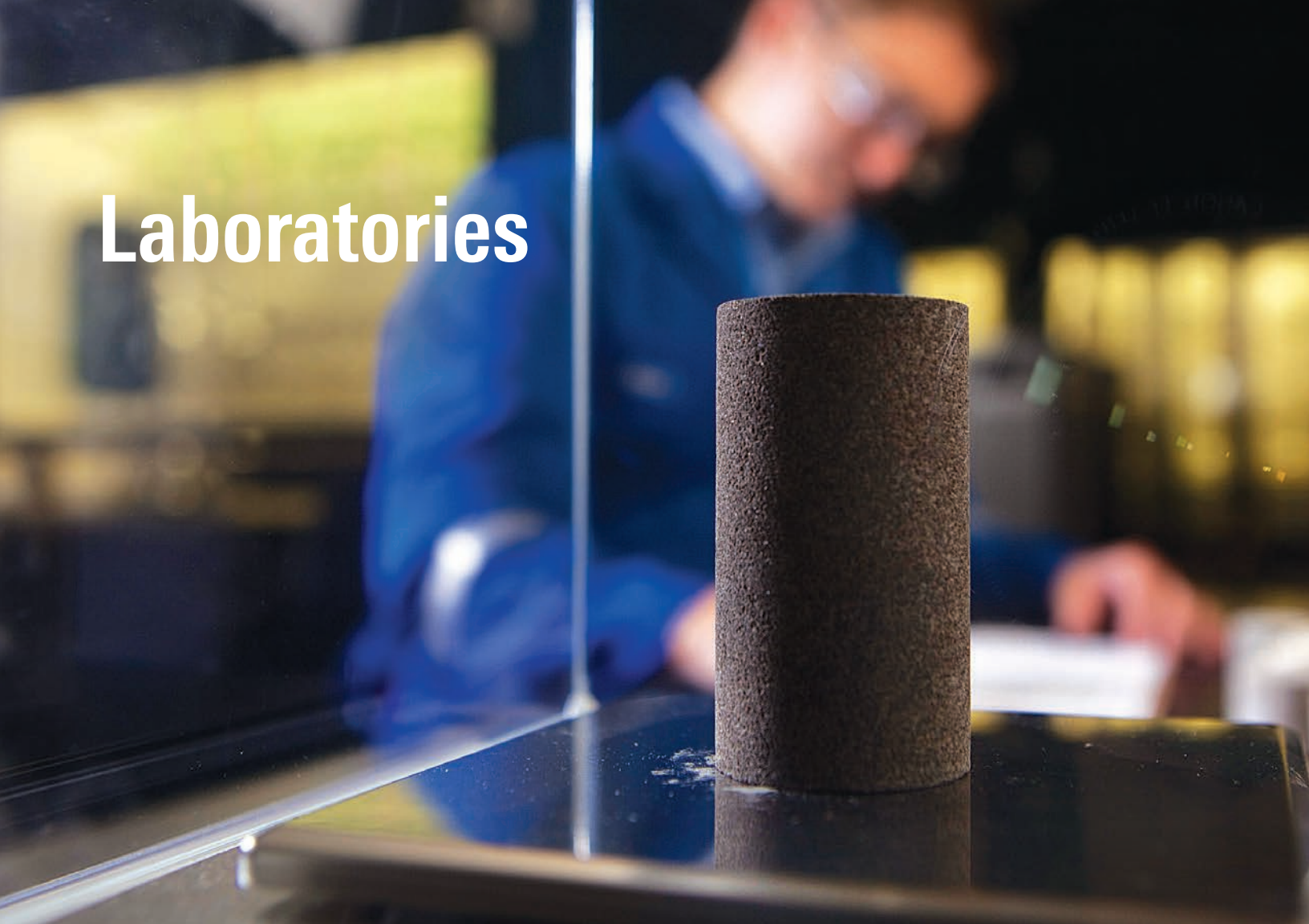
The value of **integrated rock and fluid analysis** is demonstrated in our EOR services.

Laboratory analysis is an important part of Schlumberger EOR services. Understanding rock and fluid properties helps engineers and geoscientists develop and update static and dynamic reservoir models and simulate the effects of different EOR scenarios.

Selecting the best EOR development path requires studying the dominating factors that affect oil displacement efficiency in the reservoir. These factors include capillary, gravity, and viscous forces. A successful EOR program blends an understanding of these forces and the interaction of the injected fluid with the rock and reservoir fluids.

Laboratory services and other capabilities contribute to evaluating the full array of flooding methods. Core-flow and sandpack studies can be performed for any scenario. Slim-tube and rising-bubble methods are used to evaluate miscibility conditions, while multiple-contact miscibility, interfacial tension, contact angle, and viscosity measurements complete our offering. Chemical flooding includes polymer, surfactant, alkali, and combinations of those media. Our laboratories are geared to evaluate different combinations of chemicals, the optimal salinity, and surfactant adsorption onto the matrix.

Laboratories



Schlumberger Reservoir Laboratories are distributed across the globe to support a wide range of customer reservoir characterization projects.

Throughout our laboratories, the quality of analysis is ensured by highly trained and qualified technologists, including subject matter experts on a growing range of rock and fluid specialties. Our approach of hiring the best people and providing them with advanced training enhances our development of engineers and specialists with expertise in both rock and fluid analysis. The result is analysis with uniquely valuable perspectives.

Standardized processes built on industry best practices further support data quality and efficient, accurate analyses.

Scientific rigor and attention to detail enable us to provide high-precision measurements and insightful information that can help you better understand your reservoir. This improved understanding is a proven path to better drilling, development, and production decisions.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Fluids
Rocks and fluids
Rocks

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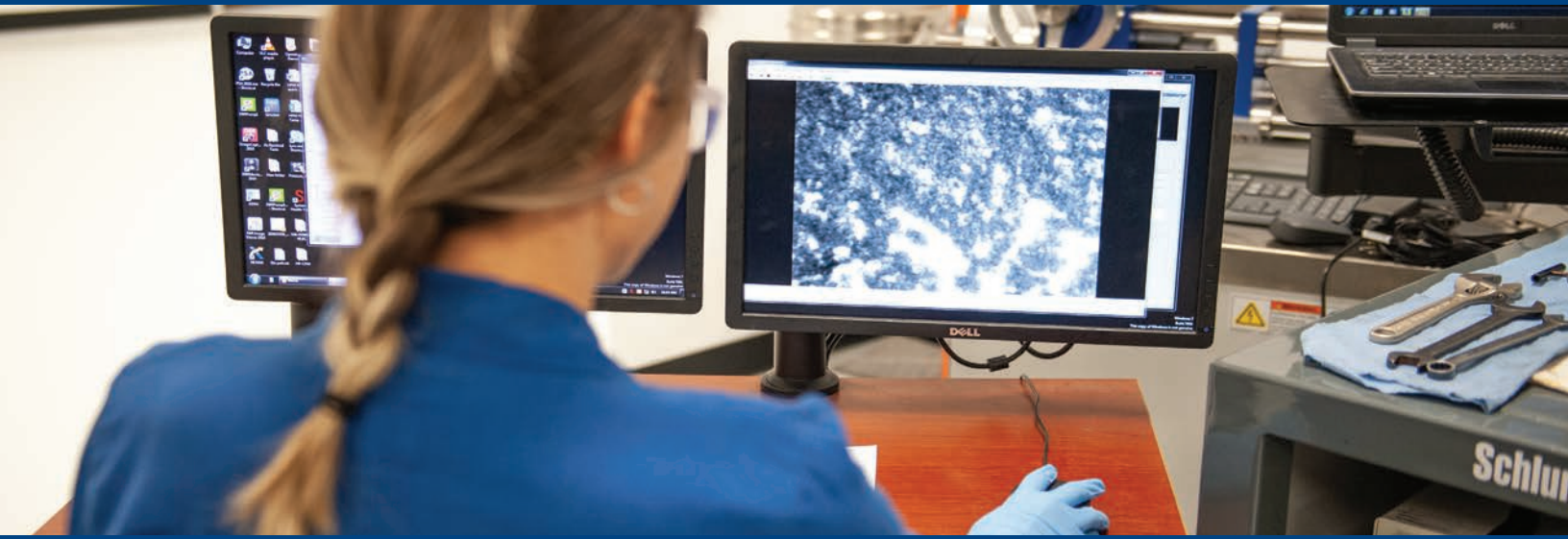

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