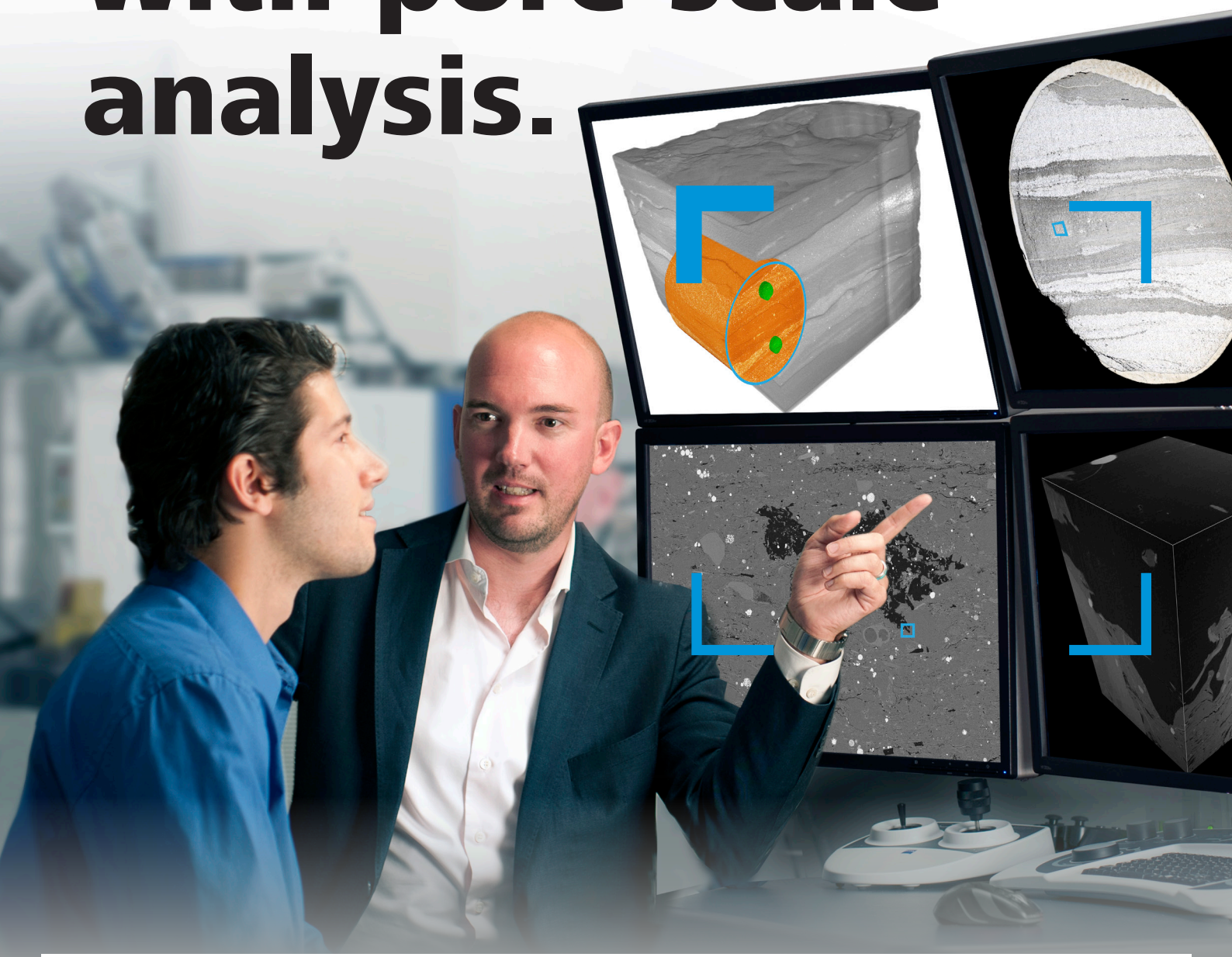
Understanding reservoir behavior with pore scale analysis.

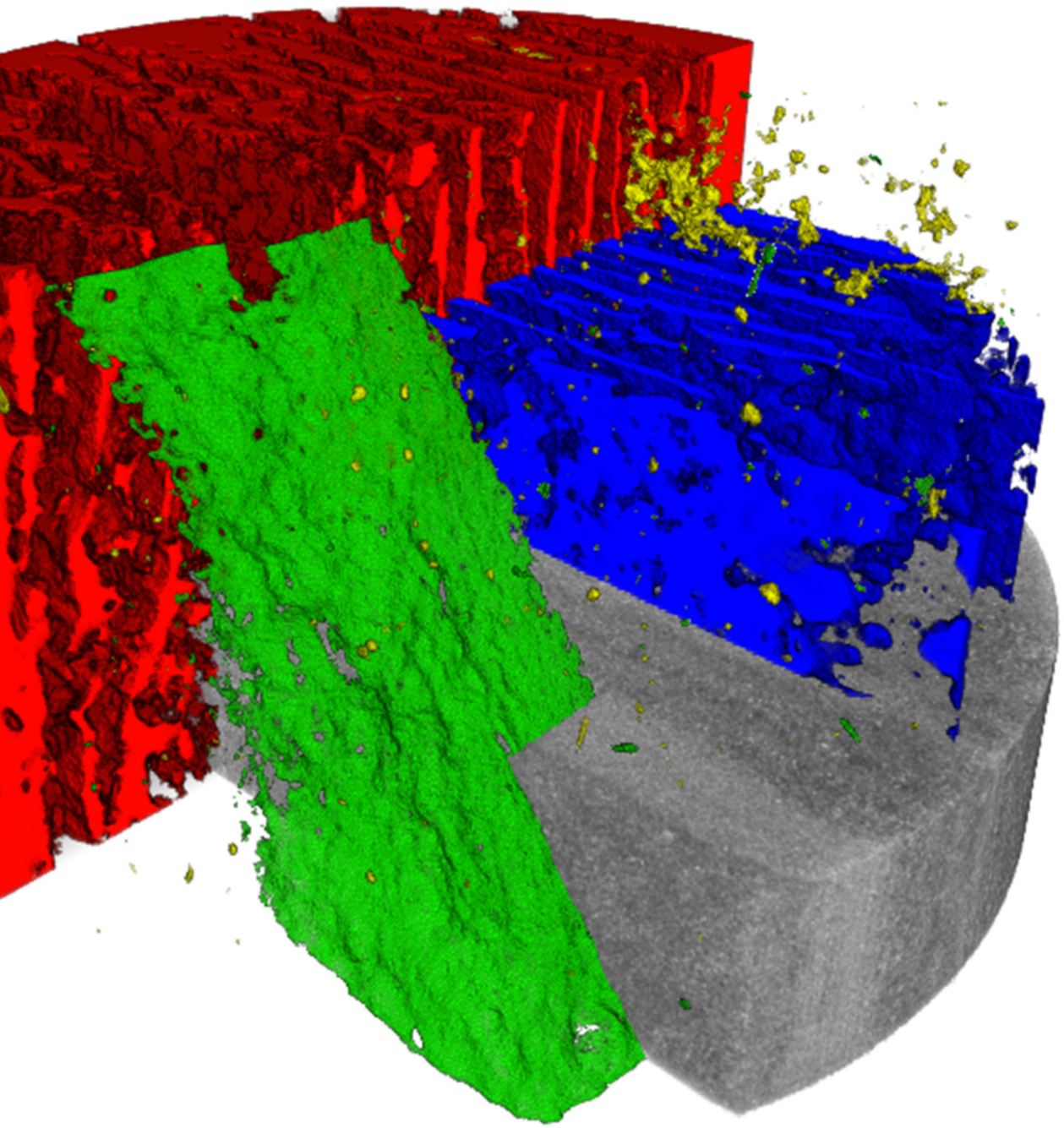


ZEISS Microscopy Solutions for Oil & Gas

ZEISS

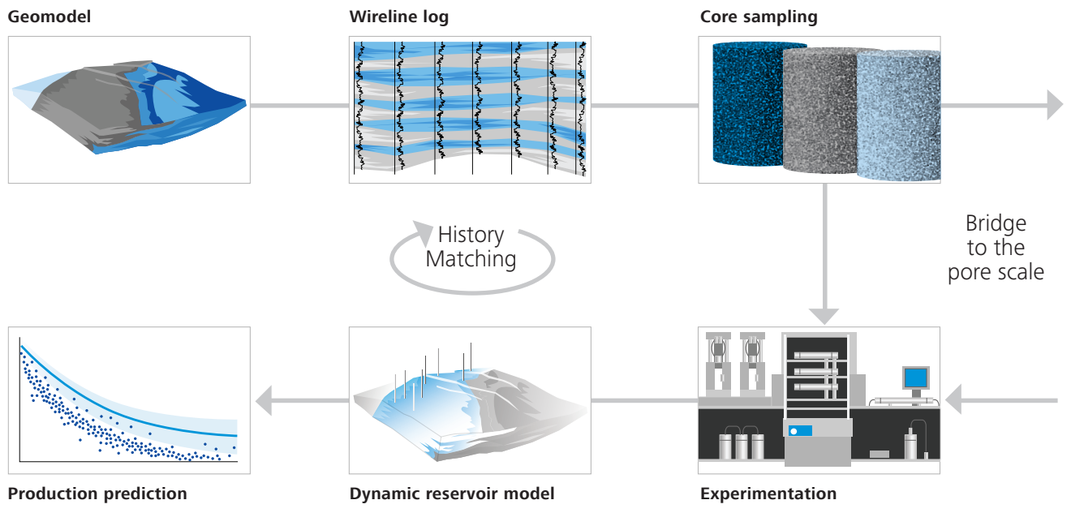
Seeing beyond

zeiss.com/oil-and-gas



Oil & Gas

The flow of oil and gas through subsurface reservoirs is governed by the scale of the tiny, tortuous pathways in the rock through which low occurs. While frequently the fundamental pore, grain and mineralogical structures can be understood at these tiny scales, this often comes at the expense of a field of view representative of real geological structures. These structures can exhibit heterogeneity ranging from the kilometer to the nanometer scales. The ZEISS portfolio of light, X-ray, electron and ion microscopes is uniquely capable of solving these multiscale and multi-physics challenges, fusing, integrating and correlating data together and even observing reservoir processes directly *in situ*. This enables, for the first time, all pore scale information to be acquired based on macroscopic heterogeneity, and all the resulting insights to be directly and quantitatively upscaled to the core plug and whole core scales.



Digital Rock Physics & Core Analysis

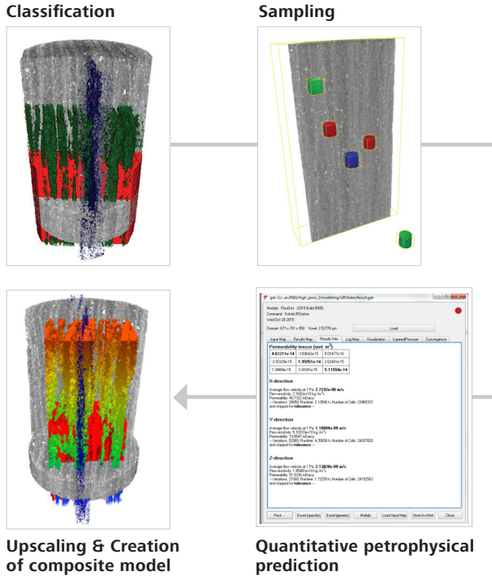
Advanced platform for multiscale digital rock physics

Pore scale modeling and simulation have developed into a crucial workflow for the oil industry where petrophysical properties (such as absolute and relative permeability) can be computed using known fluid properties and a three-dimensional representation of pore structure (frequently found using X-ray microscopy).

Such techniques, however, are limited by the size of the pore networks they are able to examine, which is in turn limited by the image field of view, traditionally limited by sample sizes. As the ultimate field of view accessible to the model is limited, so is its ability to incorporate geological heterogeneity.

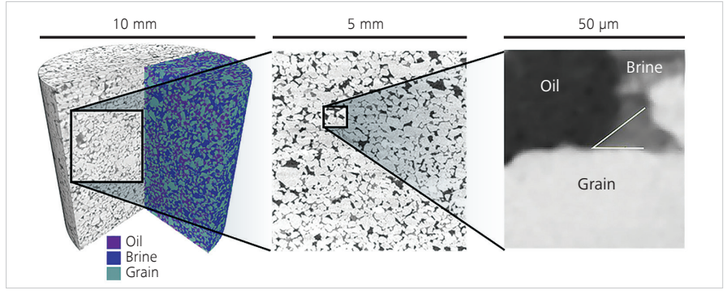
ZEISS Xradia Versa X-ray microscopes are the first non-invasive high resolution imaging systems where the achievable resolution is not limited by the sample size. This capability is enabled by the unique dual magnification architecture of the system, coupling geometric and optical magnification. This enables a Scout-and-Zoom workflow where an initial large field-of-view scan provides a digital twin of the sample at low resolution, first to quantitatively characterize and classify macroscopic heterogeneity and then to identify locations for high resolution scans. These high resolution scans are then used as an input for pore-scale models in integrated pore-scale fluid low simulation software.

The results of these simulations can be used for upscaled core-scale simulations based on the large field-of-view image. As this entire workflow is non-destructive, the sample can be used for further core-scale analysis, increasing agreement between experiments and modeling.

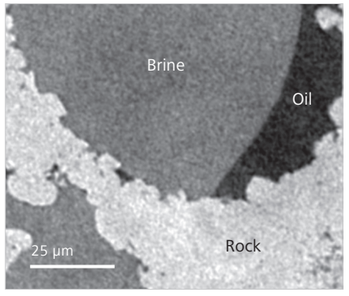


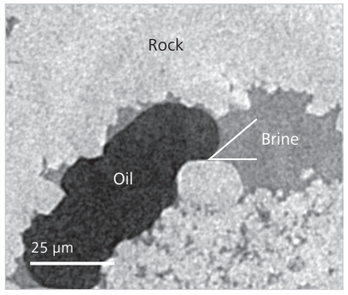
Extension of reservoir characterization workflow with advanced imaging and analysis

In situ core analysis



Multiscale in situ *imaging of steady state flow through a sandstone core.*





Wettability measurements on heterogeneous mixed wet carbonate.

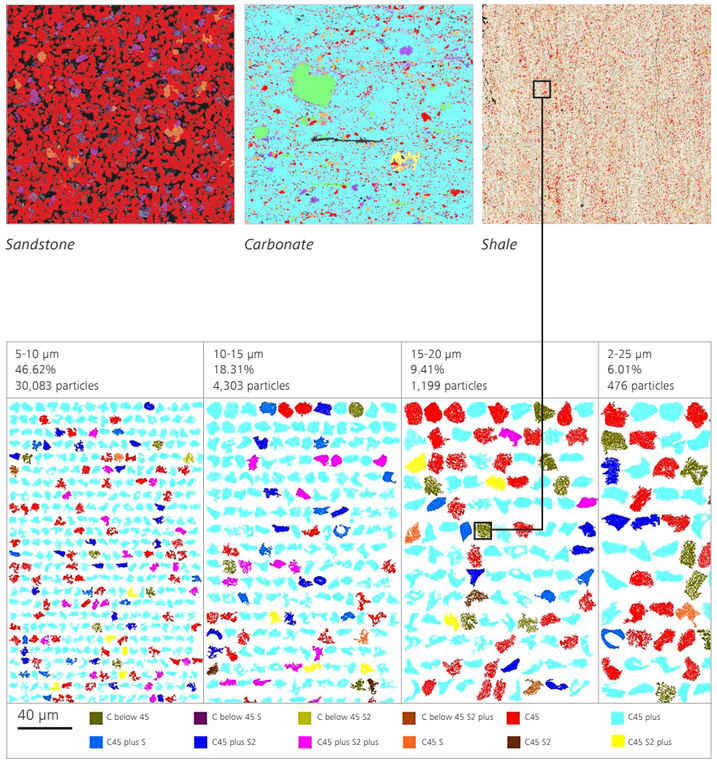
One of the most challenging aspects when examining reservoir rocks at the pore scale is that they frequently involve multiple physical processes occurring at the same time that are challenging to incorporate into a single model. For the first time, you can examine these processes directly by extending core analysis down to the pore scale to examine fundamental low physics, including wettability changes, relative permeability, pore occupancy, mineralogy changes and reactive processes with *in situ* techniques. ZEISS offers a range of *in situ* solutions for X-ray microscopy,including integrated relative permeability measurements, geomechanical experiments and a flexible *in situ* integration kit, providing a universal platform for a wide range of *in situ* experiments. These solutions can solve a wide array of problems, from the dynamic imaging of low processes to the characterization of wettability distributions in whole core mixed wet carbonate samples, to the imaging of pore scale fluid distributions within a 1" core plug. Integrated geomechanics can be used to directly image grain scale deformations to yield more information with *in situ* study. Deformations can be examined both qualitatively and quantitatively to determine key grain scale mechanisms, which can then be used to guide the creation of pore scale digital rock models. As these models better incorporate pore and grain scale physics, they can then better predict macroscopic behavior.

Mineralogical Analysis

Quantitative mineralogy

One of the greatest challenges facing petroleum engineers attempting to characterize the low and geomechanical properties of subsurface reservoirs is that of mineralogical heterogeneity. Manual techniques (such as thin section analysis) are challenging to scale and automate, so increasingly engineers are turning to automated mineralogical analysis using energy dispersive spectroscopy (EDS) analysis on a high resolution scanning electron microscope. Traditional techniques using spectral correlation to compare the EDS spectrum to a database for assigning mineral identification on a pixel-by-pixel basis is challenged to differentiate subtle changes in mineralogy (e.g., clay composition), which may have a great impaction fluid low or response to salinity change.

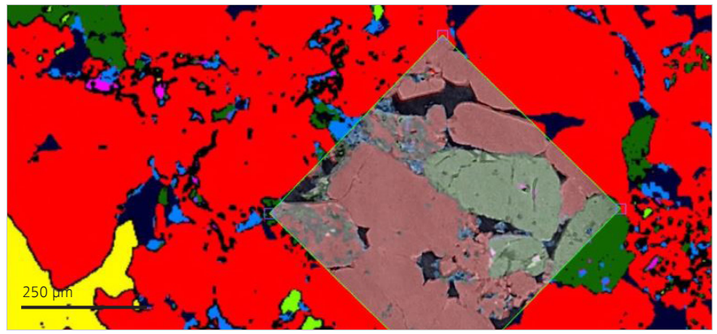
ZEISS transforms mineralogical analysis with the only fully-quantitative mineralogical mapping system – the patented ZEISS Mineralogic Reservoir. Now you can achieve a full chemical description of the reservoir rock as well as a map of each individual mineral and a range of grain-by-grain information, including grain size distributions,textural and lithological granular classification and morphological measurements.



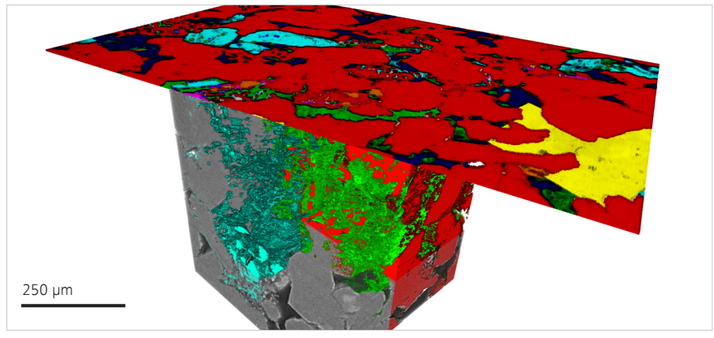
Grains, including organics, may be viewed independently or organized and sorted by measured physical parameters.

3D mineralogy

Couple 2D quantitative mineralogical analysis and correlate with 3D X-ray microscopy to extend information about local mineralogical identification into 3D. First, scan a sample using the ZEISS Xradia Versa X-ray microscope at high resolution. Then, import this data into the ZEISS Atlas 5 correlative workspace. Next, measure quantitative mineralogy on the same sample and correlate to the region examined by X-ray. This permits the 3D image to be fully-classified into different mineral groupings, giving much more reliable bulk mineralogy measurements, as well as 3D clay connectivity and even wettability distributions for 3D modelling.



Integrate multiscale, multimodal images using ZEISS Atlas 5 with X-ray and electron microscopy for 3D mineralogy.



Rendering of 3D mineralogy by correlating 2D chemical information from quantitative EDS mapping with 3D structural information from X-ray microscopy.

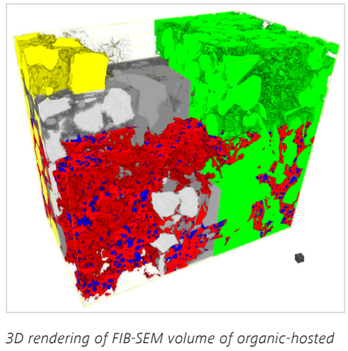
Rock Characterization

Correlative techniques & the heterogeneity challenge

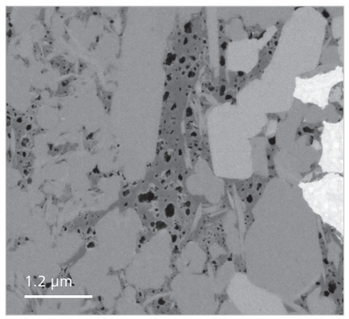
Complex subsurface systems, particularly unconventional resources, are dominated by nanoscale pore structures such as organic-hosted porosity, complex pyritization and inter/intra-granular microporosity. Such structures are often highly heterogeneous, and frequently the resolution sufficient to image them comes at the expense of a truly representative field of view.

ZEISS light, X-ray, electron and ion microscopes are uniquely capable of solving this challenge. Image large areas without sacrificing resolution 5-10X faster than traditional “tiling” techniques using the Atlas correlative workspace (up to 50,000 x 40,000 pixels) on ZEISS electron microscopes. This, coupled with industry-leading beam and detector stability, means large area scan be imaged with minimal user interaction.

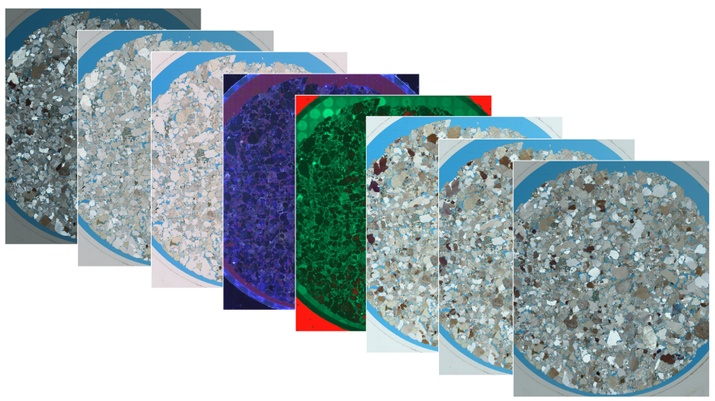
You can also rapidly digitize reservoir rock samples to extract reservoir-quality indicators such as macro & micro porosity, grain size and sorting, and mineralogy. Share virtually with multiple global collaborators. Image up to 50 standard petrographic thin sections under various contrast modes using the high through-put ZEISS Axio Scan.Z1 microscope platform.



3D rendering of FIB-SEM volume of organic-hosted porosity from subsurface onshore US shale, imaged using 2.5 x 2.5 x 5 nm voxels. Kerogen-hosted porosity is shown in blue, kerogen in red, quartz in green and pyrite in yellow.



Directly measure porosity without worrying about pore-back issues with multi-detector blending, and couple chemical and structural information together using 3D EDS mapping on Atlas 5. Imaged at 2.5 nm pixel size.



Full slide image mosaics of a sandstone petrographic thin section imaged at 20X under multiple contrast modes.

Into the third dimension

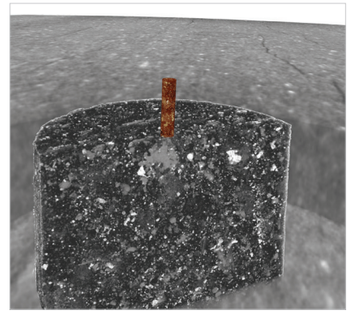
Light, electron, X-ray and ion microscopy solutions from ZEISS are exclusively equipped to solve the pore scale challenges you face. You can solve the principal issues associated with pore-scale analysis, those of heterogeneity and scale, by extending and integrating multimodal analyses over scales ranging from the whole core to the nanometer. Use multiscale workflows coupled with novel pore-scale core analysis workflows to solve problems where subsurface physics is poorly understood, such as when trying to understand the wettability distribution in heterogeneous mixed wet systems.

Extend rock characterization techniques to perform nanoscale 3D imaging using focused Ion beam-SEM on the ZEISS Crossbeam series. Industry-leading beam currents and stability as well as a unique imaging-while-milling capability allow imaging at greatly increased throughput, meaning that you can acquire larger, more representative volumes at nanometer resolution (40x40x40 µm). Patented, real-time tracking technology enables nanoscale isometric voxel sizes.

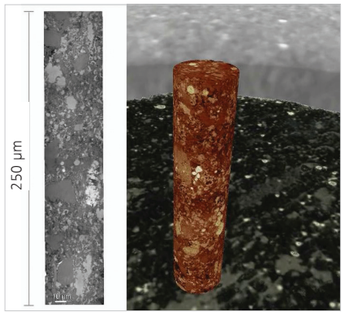
This method also enables real-time slice registration, which minimizes the loss of data from post-acquisition registration and subsequent cropping. This integrated capacity offers a step change in your capability to understand subsurface processes, allowing you to investigate reservoir rocks, and the oil and gas that low through them like never before.

Multiscale correlative analysis of a 1-inch shale end-trim

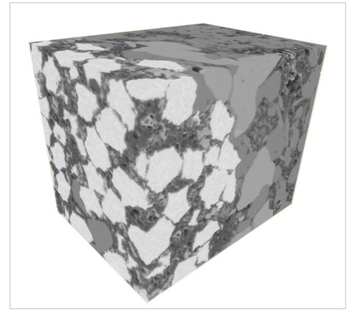
ZEISS Xradia Versa X-ray Microscope (XRM) – 24 µm voxel size



ZEISS Xradia Versa XRM – 0.7 µm voxel size



ZEISS Xradia Versa submicron and Ultra nanoscale XRM – 65 nm voxel size



ZEISS Crossbeam 550 FIB-SEM – 2.5 nm voxel size

Geoscience Education

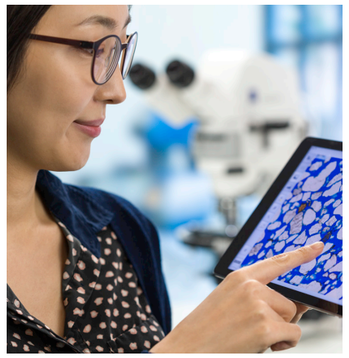
Training the geoscientists of tomorrow

Training the geoscientists of the future is essential for the health of geoscience as a whole. The ZEISS teaching microscope portfolio offers a software platform enabling efficient and shared learning.

Modern geoscience education is focused primarily on data interpretation rather than the process of data acquisition. This has led to the demand for a greater focus on data sharing and interaction and a simplification of the hardware used to produce the data itself.

The rise of distance learning also drives a need for remote control and use of image and analytical data. In the university environment, blended learning is a growing application that incorporates both optical and electron microscope data to complement the subject you are teaching. A good understanding of geological sciences is grounded in a competence for using the available instrumentation toolbox. Simplifying the learning process by using a common control software package across instruments makes the interpretation of data available to a wide audience simultaneously.

Digital Classroom – WiFi-connected Primotech



Use a tablet to display images from any WiFi-enabled microscope in a hive. Annotate, share, and save images in collections using a tablet as the control device.

ZEISS has a broad range of optical micro scopes supporting typical undergraduate techniques. As a pioneer of the digital classroom concept, several ZEISS micro scope cameras are WiFi-enabled. You can now control platforms remotely over a network to present data, sharing with a distributed audience, projecting images and their annotations via modern mobile devices with the ZEISS geo-science educational portfolio.

Blended learning, incorporating data from a whole range of sources into the teaching environment with ZEISS correlative solutions, enables you to easily communicate concepts using practical examples.

Available on the App Store Matscope

ZEISS Products for Oil and Gas Research

Xradia Versa 3D X-ray microscope with FPX
High resolution, non-destructive imaging of geological samples, including very large and precious samples.

ZEISS Xradia Context CT Imaging
3D non-destrucative large sample imaging at full field of view.

Xradia Ultra Nanoscale XRM
Virtual core analysis providing nanoscale pore structure measurements.

Crossbeam FIB-SEM
High throughput 3D analysis and sample prep. Integrated imaging and analytical solution for understanding the challenges of flow and transport in unconventional resources.

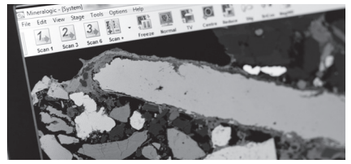
Sigma 300 field emission scanning electron microscope with Mineralogic Reservoir
Greater analysis flexibility and simpler workflows in the characterization of ores and sediments.

EVO scanning electron microscope
High stability analytical design, three chamber sizes, flexible port configuration options and compatible mineral analysis software make EVO your scanning electron microscope for analyzing morphology, mineralogy and composition of geological samples such as shales, sandstones and carbonates.

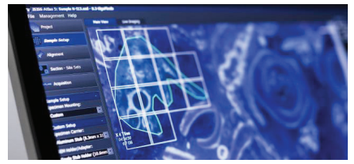
Axio Scan.Z1 slide scanner for brightfield, fluorescence, and polarization
High throughput digitization of reservoir rocks for indicators such as macro and micro porosity.

Axio Imager 2 for polarization with multi-phase software
Tailored to demanding analysis tasks. Benefit from crisp images, high optical performance and an automated workflow.

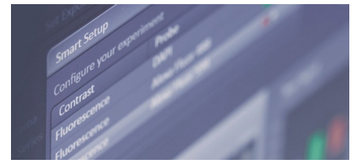
Primotech wireless hive optical microscope
Wi-Fi enabled teaching microscope with tablet support and app control. Enables social viewing of images under the scope and has the ability to act as a node in a hive of teaching microscopes or as the teacher's microscope in the digital classroom.



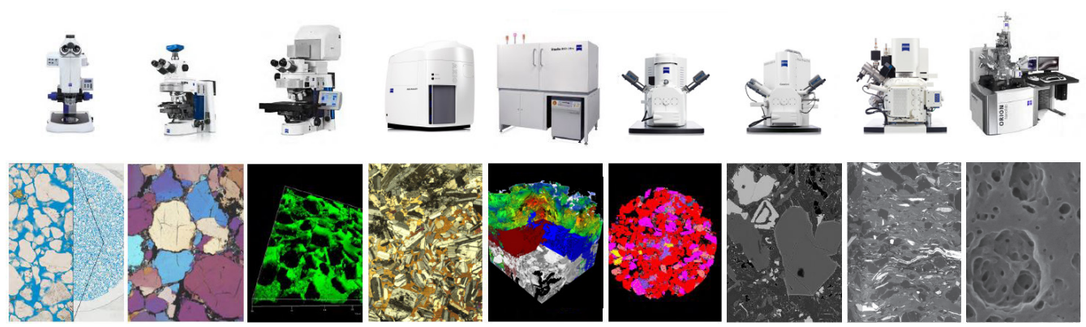
ZEISS Mineralogic
Automated mineralogy software for digital petrophysical analysis. Characterize rock texture with submicron precision using the industry standard in oil and gas automated mineralogy. Compatible with SEM and FIB-SEM microscopes.



ZEISS Atlas 5 Correlative microscopy workspace
Correlative microscopy for multi-scale, multi-modal, multi-dimensional imaging and analysis. Blended learning workspace enables remote control of instruments and collaboration across geographies and imaging modalities.



ZEN (ZEISS Efficient Navigation) and ZEN Browser
Single user interface found on all light microscopes. Simply and quickly get to result with repeatability and reproducibility.



Stereo Microscopes | **Polarized Light Microscopes** | **Confocal Microscopes** | **Digitization Microscope** | **3D X-ray Microscopes** | **Automated Mineralogy** | **Scanning Electron Microscopes** | **FIB-SEM Microscopes** | **Charged Ion Microscopes**

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