# Imaging and Computing the Physical Properties of Gas Shale

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## Summary

Managing uncertainties is vital for the economic assessment of exploration, appraisal and development of a field. A key factor resides in the integration of data at different scales. This paper will focus on an integrated DRP (Digital Rock Physics) workflow from pore to core using multi-scale x-ray CT imaging.

In gas shale, understanding of the internal pore architecture down to 3 nanometer scale is crucial for accurately determining porosity, pore connectivity, total organic content (TOC) and it's connectivity, and permeability.

Different resolutions are used on gas shale samples, from macro, micro and nano scale to the newly developed FIB -SEM resolution.

The volumes obtained from macro-CT scanning used on one-meter core sections, constitutes the link between properties computed on very small samples (10 microns/diameter) and the log data.

## Introduction

Digital Rock Physics (DRP) have been successfully applied on different gas shale samples, where the knowledge and understanding of the internal pore architecture down to 3 nanometer scale is crucial for determining connected vs. unconnected porosity, TOC distribution and maturity, pore size distribution, mineralogy, sample-scale heterogeneities, computing 2 phase flow and interrelation of all properties on the same sample.

Rock properties computed at the pore scale will enable the development of detailed scaling relations between actual rock material (high resolution CT images, cuttings, plugs, cores) on the one hand, and well logs on the other hand. A systematic approach for measuring, interpreting and modeling rock properties needs to consider the scale at which the measurements have been made (Corbett, 2009).

This paper presents a new hierarchy on the multiple scale challenge that we face everyday on the integration of scales from pore to core and to reservoir size. Macro-CT imaging of several sections of one-meter core (Figure 1) constitutes the link between properties computed at the pore-scale to the layer - lamina and bed set - scale.

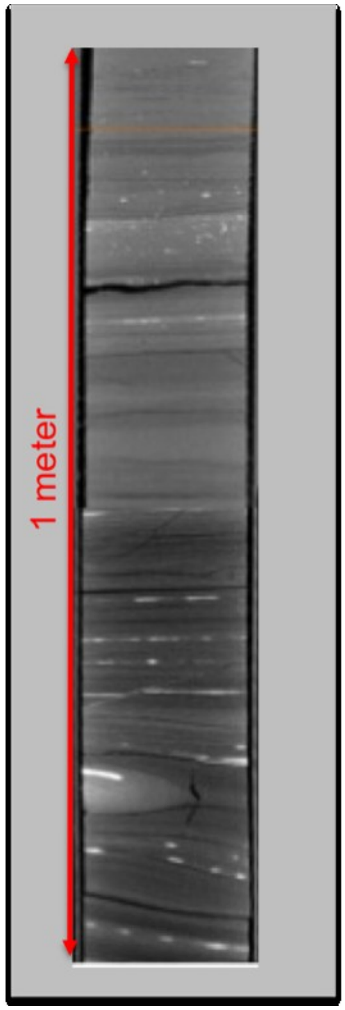


Figure 1: Cross section cut through the long axis of the 1-meter core. Dark colors represent low density material, light colors represent high density material.

## Method

Macro-CT scanning is used on several sections of one-meter core to have a quick and overall understanding of features such as layers, fractures, differential compaction, nodules, etc. Through the help of macro CT imaging one can accurately get a look inside the entire core and see the variations represented by differences in density.

The process of selecting core plugs that capture the reservoir heterogeneities is not trivial. The obtained macro-CT volumes (250 microns per voxel) guide the decisions about the location for core plug sampling in a manner that allows the user to select samples for better assessment of heterogeneities.

The selected core plugs are then subjected to a descending scale of x-ray CT imaging, from high-resolution micro-CT, to nano-resolution (Figure 2), to the FIB-SEM resolution (figure 3), along with physical sub-sampling. The descending size on scanning leads to increased resolution of the three-dimensional digital core.

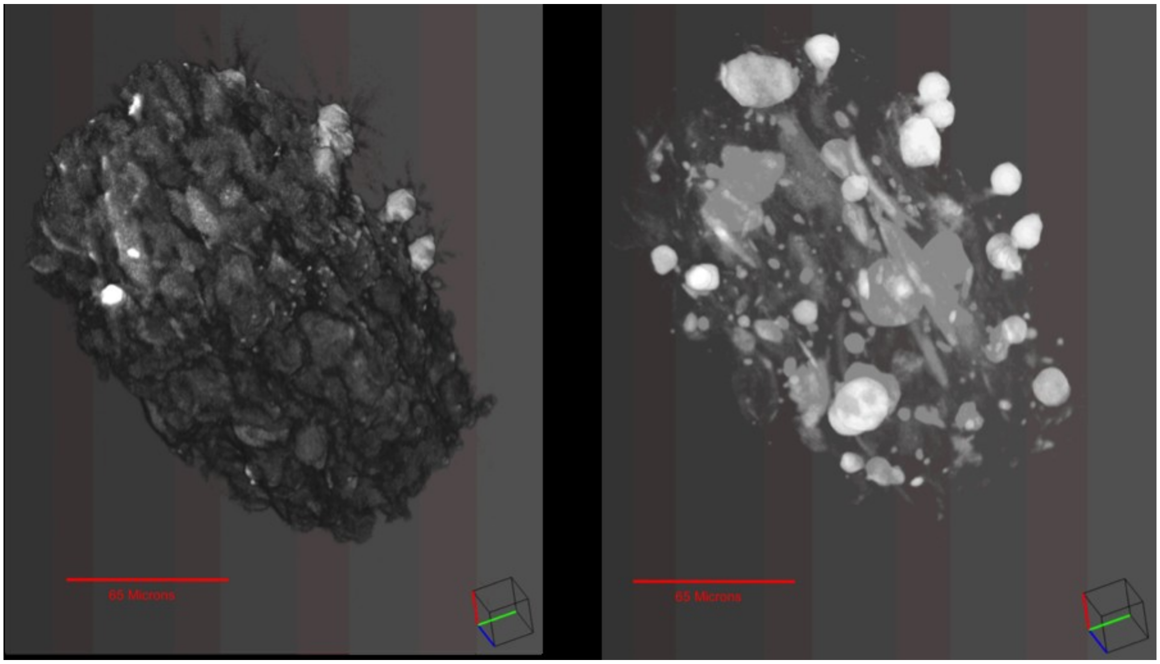

Figure 2: Left: Nano-CT volume. Right: Lower density materials removed to show preferred alignment direction of platy minerals.

By using a Zeiss Auriga FIB SEM (focused ion beam with scanning electron microscope) to acquire a high resolution 3D image on shale rock samples, this analysis can be done in days and on irregular rock material, such as drill cuttings.

We have found that the pore geometries (pores filled either with organics or free gas) in these samples fall into three groups: (a) relatively large (up to 4 micron) poorly disconnected pores; (b) large pores connected by very thin (down to 15 nanometers) conduits; (c) dual porosity system where the large pores are interconnected by large conduits and very thin conduits are interconnected and also connected to the large pores.

Within each of these three categories, the pore space may be (a) completely filled with organics or (b) partially or completely filled with gas. The latter is of most interest as it is a gas source

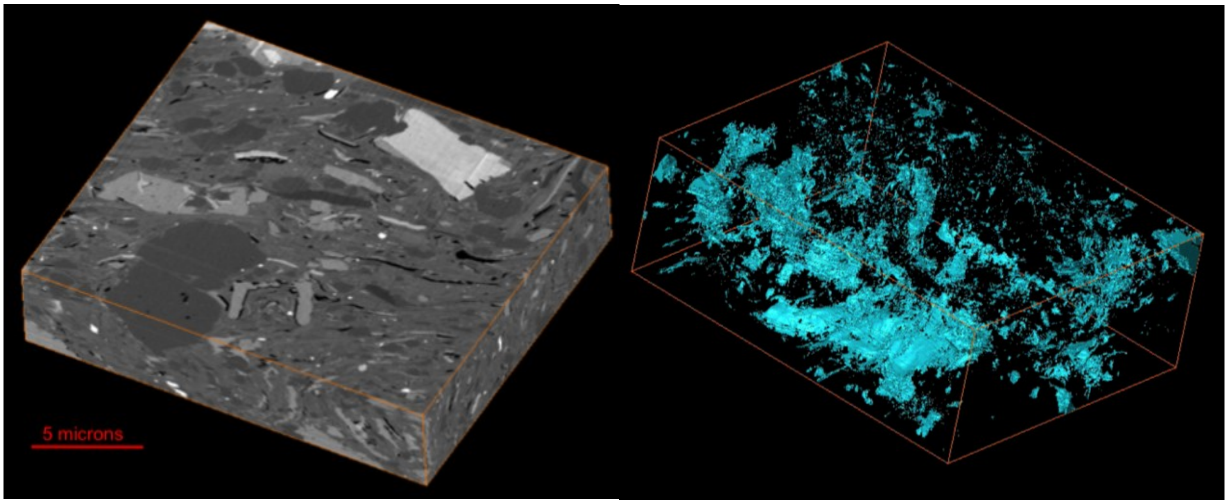


Figure 3: Left: FIB-SEM volume. Right: Pore Structure

## Conclusions

In shale rocks, we observe various geometries of pore space, including (a) disconnected pores situated in the organics and (b) connected pores within the organics. Such pores or gas pockets may be problematic to produce unless they are connected to the transport system made of thin conduits. Moreover, these conduits have to be filled with gas rather than plugged by organics. In our samples we observe both situations. In all our observations, the TOC, open pore volumes, as well as pore-space connectivity are not just qualitatively estimated from the images but rather quantitatively computed for a given sample. This three-dimensional quantitative analysis is essential because conventional 2D images cannot provide true porosity and/or TOC connectivity.

## References

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