Eagle Ford Shale Reservoir Properties from Digital Rock Physics

Joel D. Walls, Elizabeth Diaz, Naum Derzhi, Avrami Grader, Jack Dvorkin,
Sarah Arredondo, Gustavo Carpio
Ingrain Inc., Houston, TX
info@ingrainrocks.com
and
Steven W. Sinclair
Matador Resources Co., Dallas, TX, USA

Introduction

This presentation describes an integrated Digital Rock Physics (DRP) process for analyzing rock properties of shales and other unconventional reservoirs at multiple scales. The process begins with whole core and progresses to smaller plug size samples, then ultimately to very high resolution 3D imaging of the pore space. This imaging, combined with unique and proprietary fluid flow algorithms, allows us to compute shale reservoir properties and provide clear 3D renderings of the pore structure.

Core samples were available from two wells in the Eagle Ford. Well A, is in the early oil window of the Eagle Ford on the northern edge of the play. Well B, near Hawkville Field, is in the late oil window.

Multi-scale rock properties analysis brings several advantages to the process of shale reservoir characterization:

- Accurate porosity determination (connected, isolated, and porosity associated with kerogen)
- Permeability in x, y and z directions
- Ability to compute relative permeability quickly
- Improved upscaling of results
- Works with whole core, core plugs, and cuttings/fragments.

Figure 1 shows a schematic illustration of the three key stages of Digital Rock Physics analysis for shale samples.

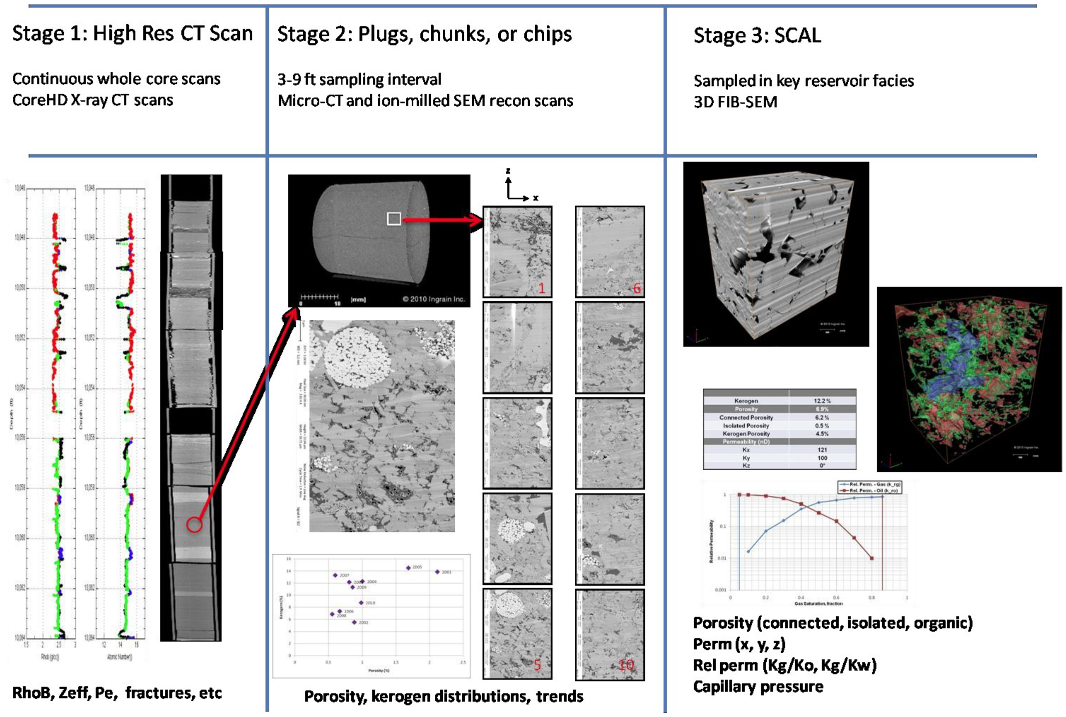

Figure 1: Schematic illustration of Ingrain's multi-stage shale reservoir characterization workflow using Digital Rock Physics. Key element is multi-scale analysis to get representative rock for 3D SCAL analysis (connected porosity, directional perm, rel. perm, cap pressure, etc.).

Objectives

The principal objective of this work was to quantify the relationships between porosity and matrix permeability for the key producing facies within the depth zone of interest. Such trends, combined with facies identification from CoreHD (whole core X-ray CT scanning), facilitate upscaling and well to well correlation. A secondary objective is to explore, and quantify if possible, the links between shale depositional facies and pore types, which are usually related to overall reservoir quality.

Scope of Work

The workflow consists of the following steps:

Stage 1: Whole core, continuous CT scanning for characterizing rock type, heterogeneity, and sampling locations

Stage 1 consists of calibrated whole core X-ray CT scanning at high resolution (about 500 CT slices per linear foot of whole core), followed by computation of separate logs for bulk density (RhoB) and effective atomic number (Zeff). The bulk density and Zeff logs provide quantitative measures to help discriminate lithology, porosity, rock facies, and depositional sequences. Figure 2 shows how the RhoB and Zeff data can be plotted to separate the well into multiple facies, and to determine which facies is most likely to be high quality reservoir. In this formation, the lowest density and lowest effective atomic number quadrant of data (green data points) probably represents higher porosity and/or higher kerogen content zones.

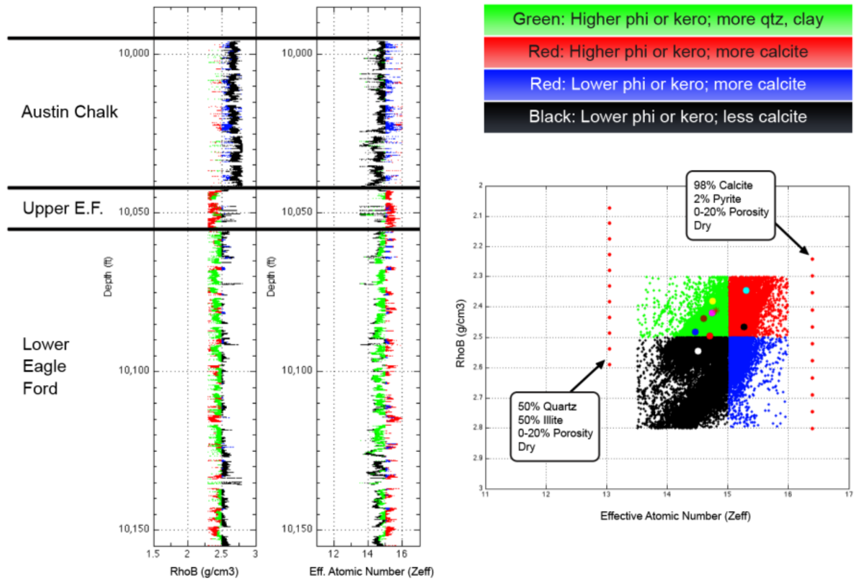

Figure 2: Bulk density and effective atomic number (Zeff) from CoreHD data is used for lithology and facies discrimination, and to aid in upscaling. This data is from Well B.

Stage 2: Plug Sample Analysis

Plug samples were taken at multiple depths based on whole core scanning in Stage 1, and information from the operator about principal zones of interest. For each plug sample, we performed both 3D CT imaging and 2D quantitative analysis. The 2D SEM analysis provides porosity and kerogen volume fraction and is also used as a screening tool to ensure representative samples for the subsequent 3D SCAL analysis. A minimum of ten 2D SEM images are used to obtain porosity and kerogen volume fraction for each plug. A diagram of the plug sample selection and analysis process is shown in Figure 3.

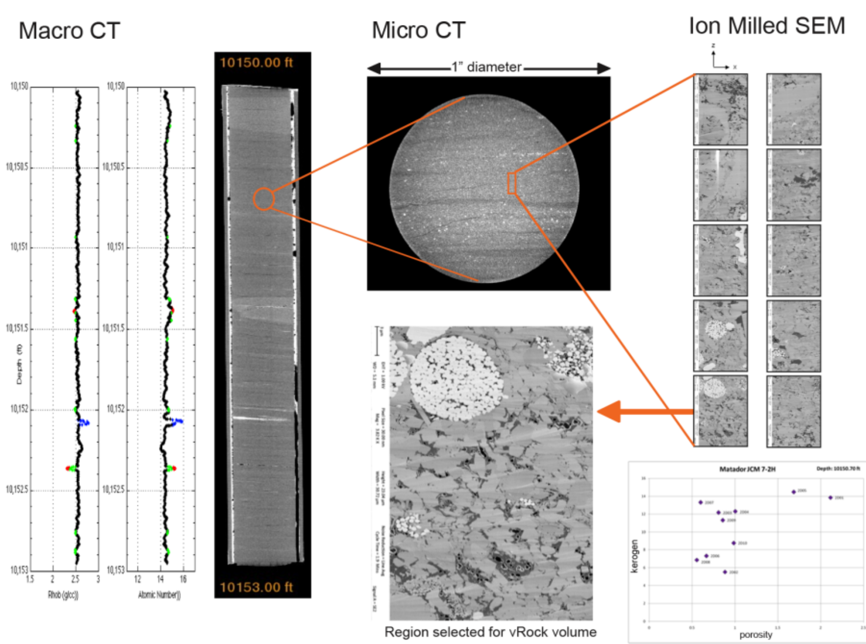

Figure 3: Diagram of the plug sample selection and analysis process using a combination of CoreHD CT whole core analysis, micro-CT scanning and quantitative analysis of ion beam polished SEM data (Well B).

Stage 3: SCAL Measurement on 3D vRocks®

The 3D SCAL analysis begins with nanometer-scale FIB-SEM pore and matrix imaging. Next comes segmentation, image processing, and creation of vRock® digital reservoir rocks. The vRock® digitized pore space geometry is used for all subsequent SCAL work so all data is obtained on the same sample. Standard analysis includes connected and isolated porosity, kerogen volume fraction and distribution, and absolute permeability in x, y and z directions.

A major objective of the SCAL process is to understand the relationships between porosity, and permeability for each of the primary producing facies. This information (as illustrated in Figure 4) is an important component in shale reservoir characterization. Digital Rock Physics (DRP) will also reveal details of the shale pore types and show which pore types are associated with higher permeability. We use the general pore description and classification system proposed by Loucks, et al, 2010. In Figure 4 it appears that organic matter porosity (porosity associated with kerogen) is especially critical to good reservoir permeability. On the other hand, those samples with more intra-granular porosity appear to have lower permeability for a given level of porosity.

The solid green and purple curves in Figure 4 were computed from a Carman-Kozeny based model that incorporates a critical porosity term (Mavko, et al, 1998). The green (lower) and blue (upper) lines are based on characteristic pore dimensions of 5 and 100 nanometers respectively. This model predicts trends in porosity vs permeability that are similar to those obtained from DRP. Data from "GRI type" crushed sample analysis tends to show lower permeability than the DRP results in the lower porosity range, but the trends appear to converge at higher porosity. This difference in porosity-perm trends between the two methods will be the subject of further study.

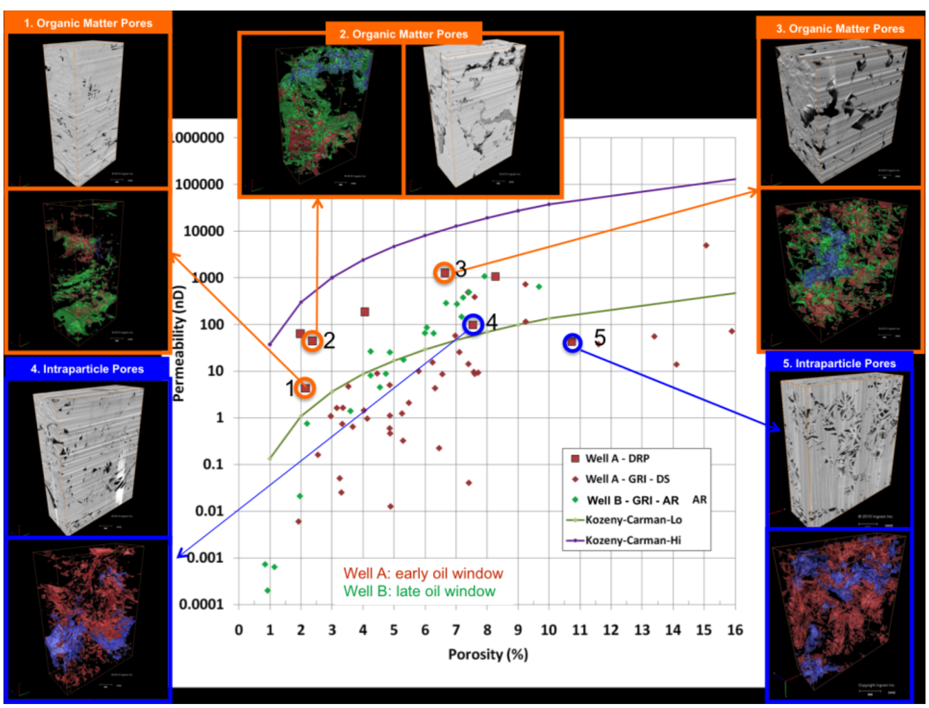

Figure 4: At higher porosity, organic matter dominated samples have better permeability than comparable porosity samples with intra-granular porosity. Special core analysis from 3D FIBSEM imaging and vRock computation can help relate facies and shale pore types to porosity permeability trends. These trends can then be integrated with facies logs from CoreHD to improve net/gross, reserves, and producibility estimates. AR = as-received, DS = Dean-Stark extracted and dried.

Summary & Observations

In this experimental study we have conducted Digital Rock Physics (DRP) analysis on whole core and plug samples from two wells in the Eagle Ford formation. This work is still under way and so the results are considered preliminary. However, the following observations can be made:

- Density and effective atomic number (Zeff) from high resolution X-ray CT scan provides detailed information on layering and facies in the Eagle Ford shale.
- Key facies changes can be readily observed from the CoreHD data, while the core is preserved in the sealed aluminum tubes.
- Plug sample locations can be selected based on key facies and lithology variations from whole core scans.
- Pore types are mainly organic matter and intra-granular.
- At higher porosity, organic matter dominated samples have better permeability than comparable porosity samples with intra-granular porosity.

Acknowledgements

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