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Fundamentals of Porosity System Analysis in Tight Rocks

Graham Spray, M.Sc., P.Geo.
AGAT Laboratories

Abstract

Porosity in tight rock formations is a key petrophysical property and critical for understanding fluid storage and flow characteristics. Shale porosity is typically divided into microporosity (diameter <2.0nm), mesoporosity (2-50nm), and macroporosity (>50nm). The relationships between porosity and permeability are controlled by rock texture and the degree to which the porosity system is interconnected or isolated (effective vs. ineffective). Porosity in tight rocks such as shales is typically characterized in the laboratory using helium pycnometry (for total effective porosity), and mercury injection porosimetry (MICP), and/or gas adsorption (BET theory) for pore throat size distribution. These methods are effective but cannot provide information on the associations between porosity and the textural and mineralogical properties of a rock.

In shales, porosity is commonly associated with organic macerals, fractures, and the rock matrix (intercrystalline pores between tectosilicates, and between matrix clays), and occasionally intracrystalline pores between clay sheets. Pore spaces can also occur in particular geologic contexts such as between the sub-crystallites of pyrite framboids. The mineral and rock texture associations of porosity in shale are an important part of reservoir characterization, and petrographic imaging is the best way to investigate these associations. Due to the nanometer to micrometer size range of shale pores, standard optical petrography is insufficiently powerful to image these pores. Scanning Electron Microscope (SEM) petrography can provide useful textural information and overviews, but standard SEM systems using thermionic tungsten filament electron emitters still cannot achieve the magnification necessary to image and characterize shale microporosity. While Transmission Electron Microscopy (TEM) has been used to investigate shale porosity, and excels for true microporosity (<2.0nm), TEM can be complex to operate and interpret effectively, and cannot provide broad geologic context due to extremely limited sample size. It also has demanding sample preparation requirements and minimum zoom levels are still very high, meaning that it is difficult to get broader context from TEM analysis.

Field Emission (FE-) or Field Emission Gun (FEG-) SEM systems make use of field emission electron guns that provide significantly more coherent, stable, and more finely focused electron beams than thermionic tungsten filament emitters. This, along with stronger vacuum systems, allows significantly higher magnification capability; FE-SEM systems can achieve subnanometer resolution under optimum conditions, two orders of magnitude finer than thermionic SEM systems. This resolving power allows investigation and characterization of shale macro- meso- and some micro-porosity associations, and incorporation of this understanding into reservoir quality studies. Building an understanding of porosity associations, alongside other petrophysical data, allows a more complete geologic interpretation of the nature of the porosity architecture and the effective and ineffective porosity of the rock system.

This talk aims to review the current state of the art for tight rock porosity system analysis, including discussion of total porosity, permeability, MICP, and recent advances in BET Theory, but with particular focus on advanced SEM investigations of pore systems.

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