Grain Density and Mineralogy of Hydrocarbon-Bearing Shales and Siltstones in Alberta

Introduction

Porosity in shale, siltstone, and other unconventional reservoirs is a major factor in estimating hydrocarbon resources in place. Accurately quantifying the pore space is important because the total volume of continuous unconventional plays mean that even a relatively small decrease will greatly affect resource estimation.

A common way to calculate porosity is by using density logs. This procedure uses specified grain and fluid densities. The grain density is often set at certain assumed values based on the broad lithology of the reservoir, such as sandstone, mudstone, or limestone.

The Petroleum Systems and Earth Resources Team of the Alberta Geological Survey has found that when evaluating shale and siltstone reservoirs, the grain density must be calculated for each unit and interval. Our preferred method for determining grain density is XRD mineralogy.

Density Porosity

The density porosity of an interval, \( \Phi \), can be calculated by using the equation:

\[
\Phi = \frac{\rho_f - \rho_b}{\rho_f - \rho_g}
\]

where \( \rho_f \) is the fluid density, \( \rho_b \) is the bulk density, and \( \rho_g \) is the grain density. The units are equivalent.

Importance of Grain Density

Varying the assumed grain density changes the calculated porosity. The higher the assumed grain density, the more empty volume as pore space for the same bulk density. This effect is shown here, with porosity as a function of bulk density:

Varying the assumed grain density changes the calculated porosity on the order of 2–3%. At a high bulk density, the relative effect on the magnitude of hydrocarbon storage is significantly greater at low porosity.

Grain Density from Mineralogy

There are several different analyses that can be used to find the grain density of a reservoir unit. The preferred method used in shale assessment at the Alberta Geological Survey is to use XRD-derived mineralogy to calculate the weighted average grain density of core samples. The procedure for this is as follows:

1. Convert total organic carbon (TOC) content to kerogen. The factor for this is typically between 1.0 and 1.4.
2. Ranconize the XRD mineralogy results to indicate kerogen and silt to 100% (Al).
3. Calculate the weight percent mineralogy to volume (\( V_i \)) by dividing each considered by its mineral density.
4. Calculate the volume-weighted average grain density:

\[
\rho_g = \frac{\sum_i V_i \cdot \rho_i}{\sum_i V_i}
\]

Comparison to Other Methods

To ensure that the XRD-mineralogy-derived grain densities are unbiased, the results were compared to other available data. Two other lab tests provided porosity and grain density information: helium pycnometry and Dean Stark analysis. Both tests use Boyle’s Law and measured head pressure to find the grain density and then combine with the measured mean to determine density. In a Dean Stark test, this is done after natural bulbs have been removed with tapers.

The chart below compares histograms of grain density in the Wilrich shale from the three data sources. The three distributions have the same general shapes and similar mean values. The porosimetry results have a slightly higher mean than those from XRD mineralogy and Dean Stark, but the differences are not statistically significant.

Grain Density Variations

Within larger unconventional units there is variation in grain density, if enough data is available to support it. The variation should be accounted for. Ideally each reading on a geophysical log would have its own mineralogical input for hydraulics but this is not usually possible based on data and log availability and quality.

On a larger scale, interbedded variations can be seen even with detailed data. The figures in this panel show how mineralogy and grain density vary:

- Geographically: The Duvernay Formation juxtaposed into West Shale Basin and East Shale Basin domains (other Muksu Formations are considered more or less stratigraphically equivalent units with distinct mineralogical makeups). The Duvernay Formation in the East Shale Basin is more carbon-richer than the West Shale Basin, and the Muskwa Formation to the north contains less carbonate and more quartz and clay minerals.
- Stratigraphically: The basal Bear/Exshaw is a distinct unit and equivalent to the Bakken Formation. There is an upper shale, middle limestone/dolomite, and lower shale. The drastic differences in organic content have a large impact on the grain densities.
- Lithographically: The Montney Formation is made up of mainly siltstone, but coarser and finer lithologies are also present. The makeup and grain densities can be quite different.

Variation Across Lithology

Variation Across Stratigraphic Units

Grain Density from Mineralogy

Comparison to Other Methods

Grain Density Variations

Variation Across Equivalent Units

Importance of Grain Density

Density Porosity