Steve Lyster
Dean Rokosh
Andrew Beaton
Alberta Geological Survey
402, Twin Atria Building
4999–98 Avenue
Edmonton, AB
www.ags.gov.ab.ca

Fran Hein
Alberta Energy Regulator
Suite 1000, 250–5 Street SW
Calgary, AB
www.aer.ca

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 vast sizes of continuous unconventional plays mean that even a relatively small bias will greatly affect resource estimation.

A common way to calculate porosity is to use density logs. This process 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 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 calibrated for each unit of interest. Our preferred method for determining grain density is XRD mineralogy.

Density Porosity

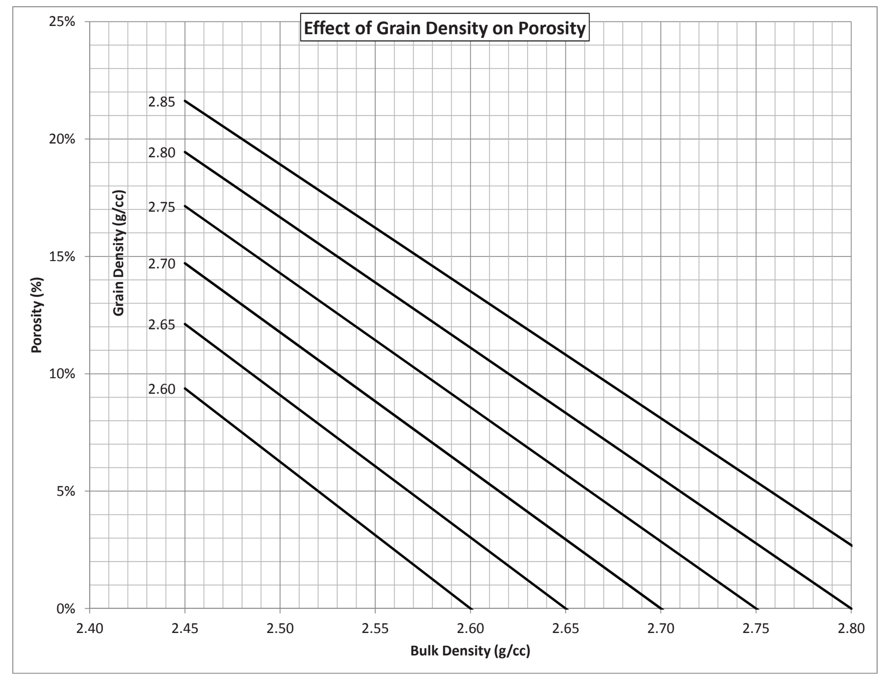
The density porosity of an interval, Φ, can be calculated by using the equation:

$$\Phi = \frac{\rho_g - \rho_b}{\rho_g - \rho_f}$$

This uses bulk density from geophysical logs (ρ_b), grain density (ρ_g), and fluid density (ρ_f).

Importance of Grain Density

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



The lines of different grain densities are not quite parallel, but they closely follow one another. At a low bulk density, corresponding to high-porosity reservoir rock, a change of 0.05 g/cc (or t/m^3, or specific gravity, the units are equivalent) changes the calculated porosity on the order of 2–3%. At a high bulk density, corresponding to low-porosity shale, siltstone, or tight sand, the same change of 0.05 g/cc in the grain density also affects the calculated porosity by about 2–3%. 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:

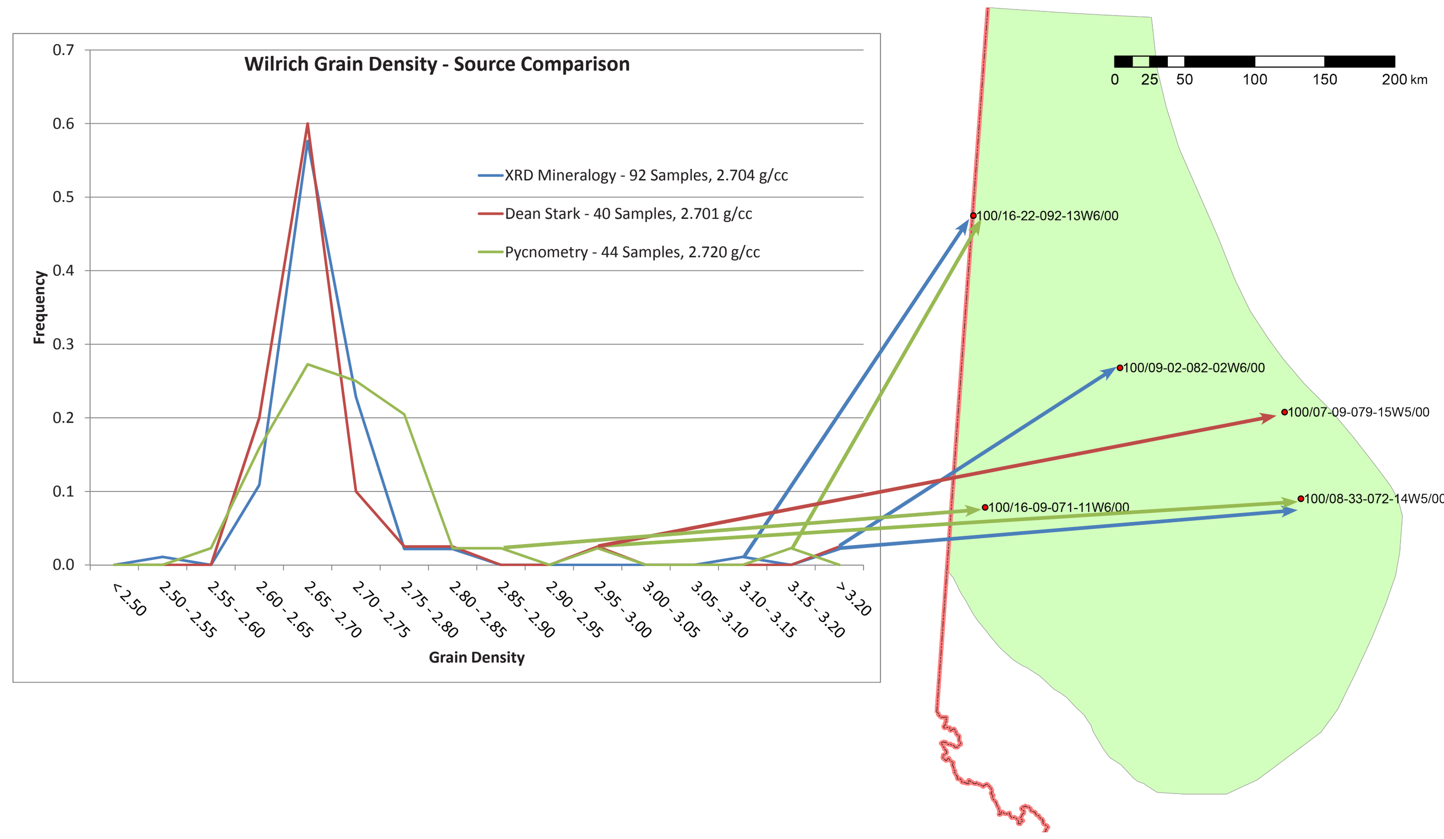
1. Convert total organic carbon (TOC) content to kerogen. The factor for this is typically between 1.0 and 1.4.
2. Renormalize the XRD mineralogy results to include kerogen and sum to 100% (W_i'). $W_i' = \frac{W_i}{\sum_{i=1}^{n+1} W_i}$ $\forall\, i=1,\ldots,n+1$
3. Convert the weight percent mineralogy to volume (V) percent by dividing each constituent by its mineral density. $V_i = \frac{W_i'/\rho_i}{\sum_{i=1}^{n+1} W_i'/\rho_i}$ $\forall\, i=1,\ldots,n+1$
4. Calculate the volume-weighted average grain density. $\rho_g = \sum_{i=1}^{n+1} V_i \cdot \rho_i$

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 helium pressure to find the grain volume and then combine that with the measured mass to determine density. In a Dean Stark test, this is done after residual fluids have been removed with toluene.

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

All three distributions display a long positive tail where a few samples have much higher grain density than the majority of the samples, from 2.80 g/cc to over 3.20 g/cc. These samples were taken from different wells in different geographic areas spread out over hundreds of kilometres. This suggests that the occurrence of high-grain-density samples is a characteristic of the unit and is not caused by a sampling bias.



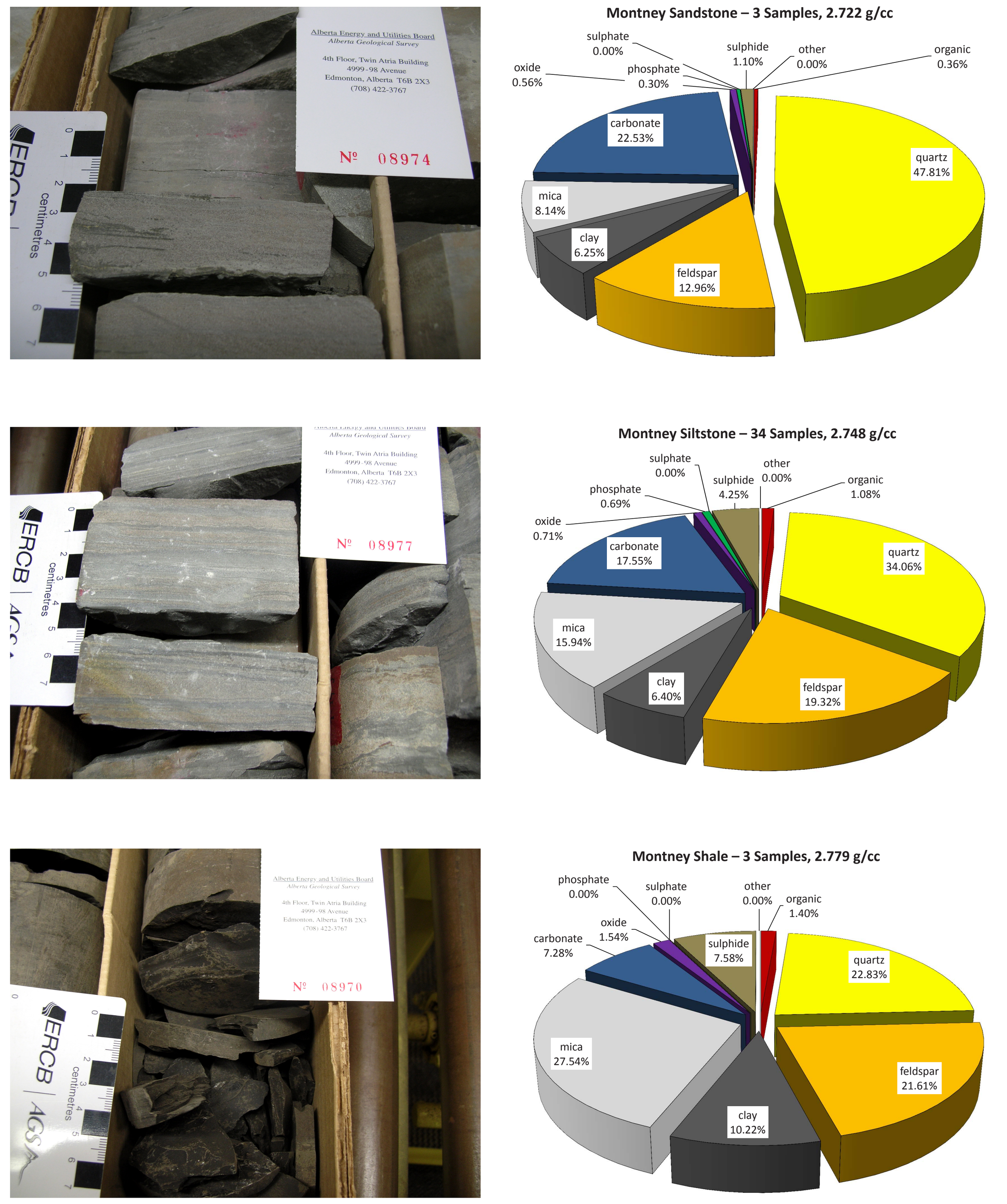
Grain Density Variations

Within larger unconventional units there is variation in grain density. If enough data is available to support it, this variation should be accounted for. Ideally each reading on a geophysical log would have its own modelled mineralogical makeup, and this would allow for a dynamically changing grain density to provide the most robust porosity estimates. This is not usually possible based on data and log availability and quality.

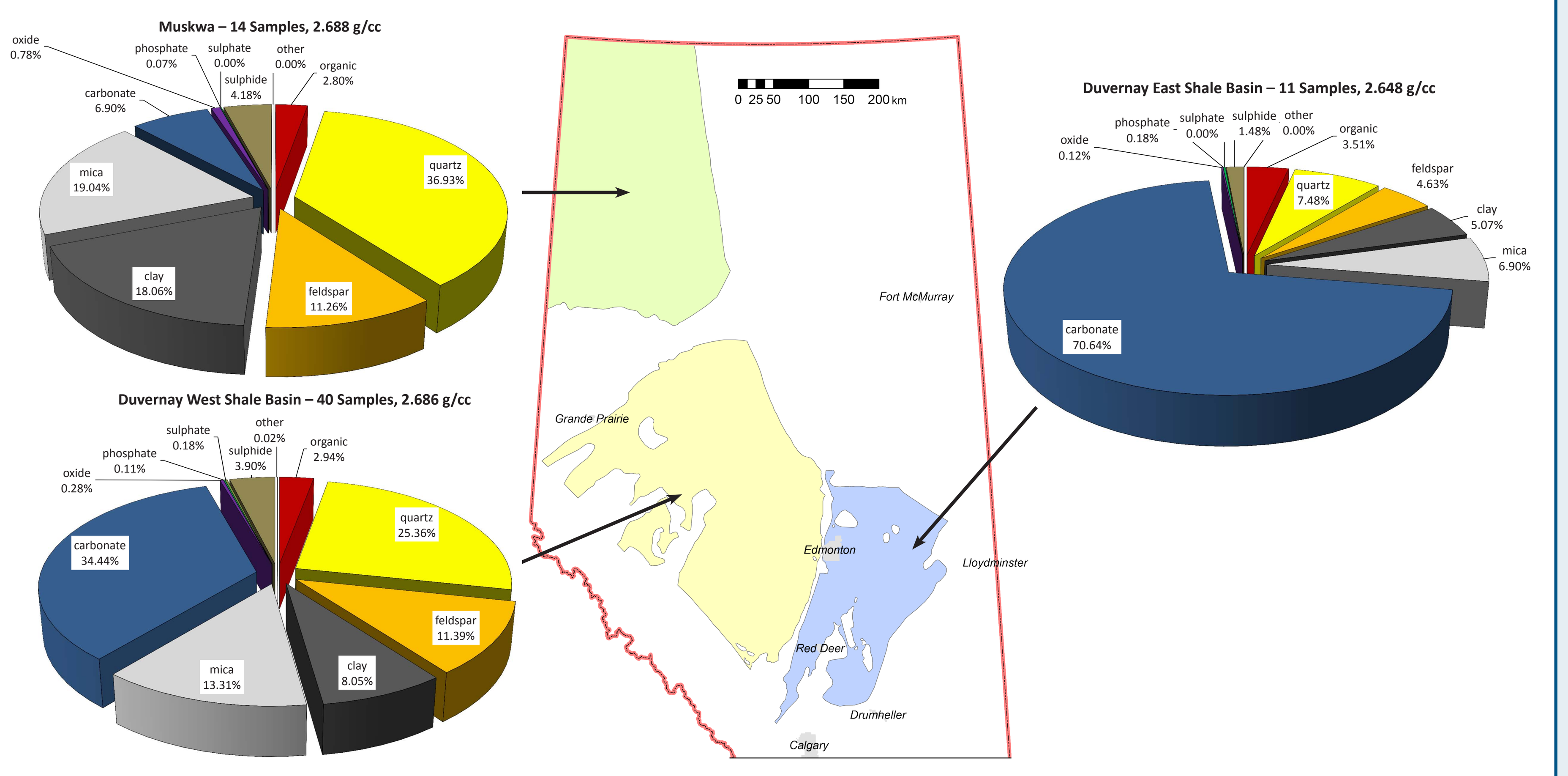
On a larger scale, mineralogical variations can be seen even with limited data. The figures in this panel show how mineralogy and grain density varies:

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

Variation Across Lithology



Variation Across Equivalent Units



Variation Across Stratigraphic Units