Mineralogy and Grain Density of Alberta Shale

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Alberta has been the most prolific conventional oil and gas producer in the Western Canada Sedimentary Basin for the past 60 years. Declining conventional production has signalled the need for the exploration of unconventional resources, and although CBM drilling is well established, shale gas drilling and production is scant. Over the last year, interest in land sales, related to shale gas and tight oil exploration, is beginning to take off in the province. Our group (Energy Resource Appraisal) at the ERCB (Energy Resources Conservation Board) has been tasked with assessing the resources in all Alberta shale. Rock-Eval and TOC analyses suggests that there are no less than about 15 relatively organic-rich formations that have shale gas potential. Alberta, however, has few shale gas wells so our resource assessment will involve significant assumptions regarding such issues as water saturation and even effective porosity. To this degree, we will be involving geostatistics to aid in quantifying uncertainty in our resource estimates.

Over the past 5 years we have collected about 1150 shale samples primarily from core in the Late Cretaceous Colorado Group (Senomanian to Santonian), Early Mississippian Banff/Exshaw Formations (Tournasian), Devonian Muskwa and Duvernay Fms. (Frasnian) and the early Triassic Montney Fm. Most of the industry interest has concentrated in the Devonian and Triassic rocks and to a lesser extent in the Cretaceous and Mississippian.

This talk will focus on mineralogy and grain density of shale in three formations that exhibit shale gas potential, namely the Duvernay, Muskwa and Montney Fms. Grain density values are a critical part of determining total porosity using density logs. A fundamental observation from helium pycnometry and bulk and clay mineralogy from our data is that grain density values derived from helium pycnometry are quite low, often resulting in little or no density log porosity in shales. This is occurring in formations that we are quite certain are gas bearing and where permeameter measurements suggest that effective porosity does exist. Furthermore, gas detection data during drilling also suggests that effective porosity in shale is evident. Our central questions are…… Is the grain density derived from helium porosity too low? What are we seeing in our mineralogy data that can help answer our question?

The Duvernay has long been regarded as an important source rock, having sourced oil and gas for Alberta's most prolific reservoirs, the Devonian Leduc Formation (Fm.) reefs and Devonian Swan Hills Fm. reefs. Perhaps the most interesting aspect of Duvernay source rock mineralogy is that much of the formation is carbonate rocks, with little shale in western Alberta, where recent land sales have occurred. Generally speaking the Duvernay primary carbonate content increases to the west. The four most common minerals in the Duvernay and the range of weight-percents are calcite 8.9-87.4, quartz 1.3-46.5, muscovite 0.0-18.3 and orthoclase 0.0-16.3 (Figure 1). Calcite and quartz are inversely correlated. The most common clay-sized minerals are quartz and calcite rather than clay minerals and in most cases we can confirm the lack of clay minerals by SEM observations.

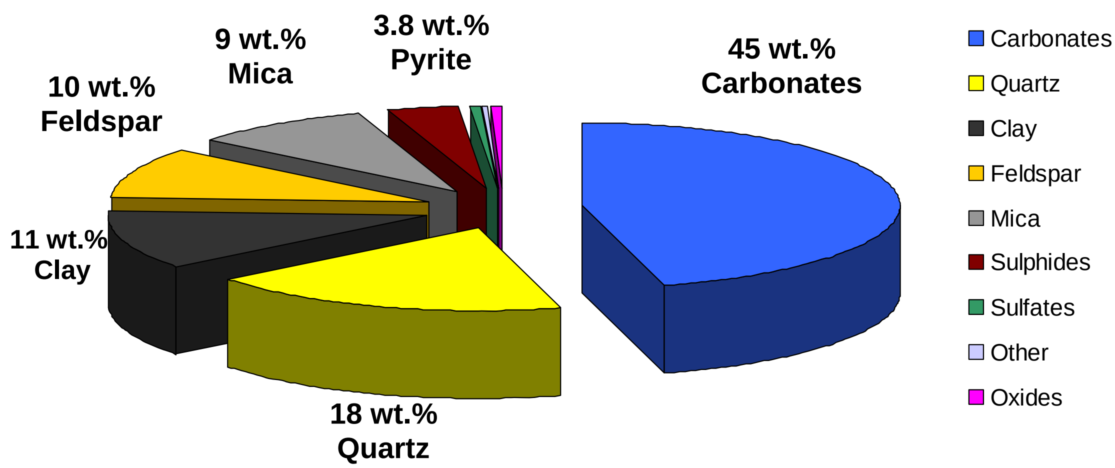

Figure 1. Devonian Duvernay Fm. average mineralogy derived from semi-quantitative XRD reconciled with XRF (16 samples).

The Muskwa formation in Alberta is the time equivalent of one of the formations being explored in the prolific Horn River Basin of Northeast British Columbia. In Alberta, the Muskwa is shallower, slightly less mature and generally thinner. Mineralogical analysis was done in the same manner as the Duvernay. The range of weight percents of the most common four minerals are quartz 28.4-50.4, muscovite, 0.0-26.7, illite 3.9-15.6 and dolomite 1.8-22.5. The most common clay-sized minerals are quartz followed by illite and montmorillinite.

The best lithological description of the Montney is a dolomitic siltstone with sandstone turbidites encased in the siltstone. Our interest is in the dolomitic siltstone. Mineralogical analysis was completed in the same manner as the Duvernay and Muskwa. The range of weight percents of the most common four minerals in the siltstone are quartz 20.7-44.7, muscovite, 3.2-31.4, dolomite 4.5-26.0 and orthoclase 0.0-22.2. The most common clay-sized minerals are quartz followed by dolomite and illite.

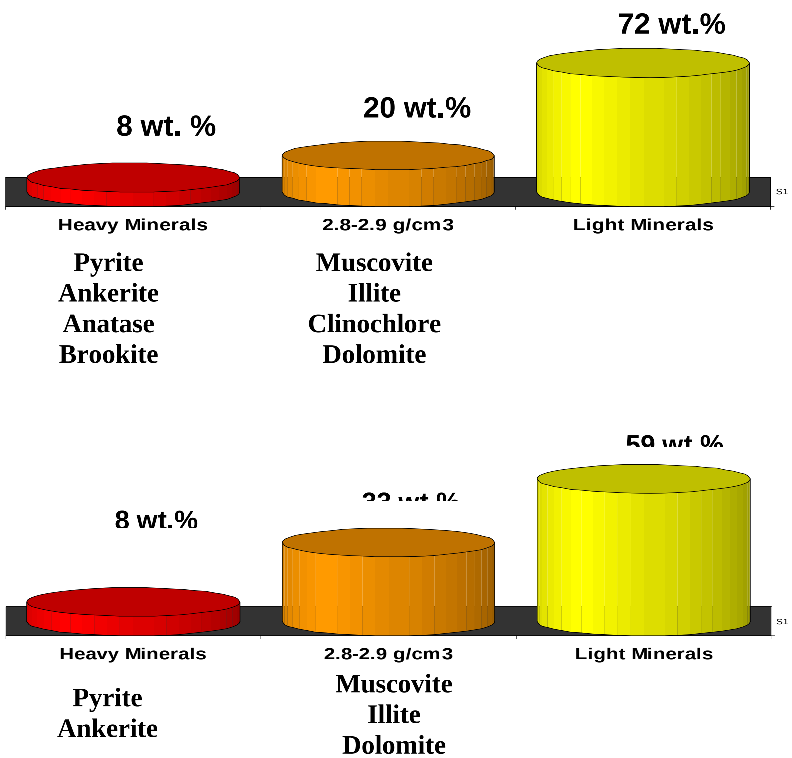

Figure 2. Duvernay and Muskwa formation heavy mineralogy. Mineralogy is determined from semi-quantitative XRD reconciled with XRF. a) Upper panel. Mineralogy of the Duvernay formation indicating 28 weight-percent of minerals greater than 2.8 gm/cc; 16 samples. b) Lower panel. Mineralogy of the Muskwa formation indicating 41 weight-percent of minerals greater than 2.8 gm/cc; 5 samples.

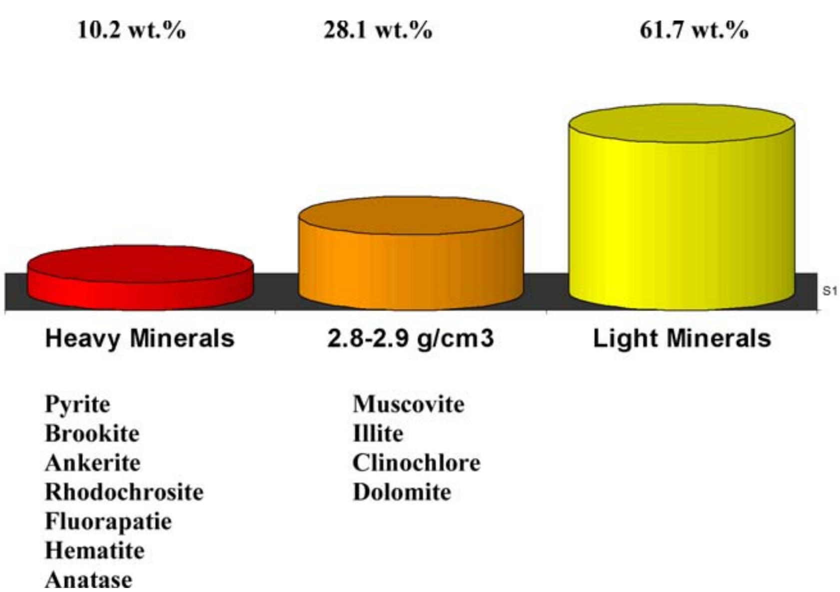

Figure 3. Montney formation heavy mineralogy. Mineralogy is determined from semi-quantitative XRD reconciled with XRF. The weight-percent of minerals greater than 2.8 gm/cc is 38.3; 11 samples.

Figure 2 reveals that about 28 wt.% of the minerals in the Duvernay have a grain density greater than 2.8 gm/cc, while 41 wt.% of the minerals in the Muskwa have a grain density greater than 2.8 gm/cc. In the Montney formation (Figure 3), 38.3 wt.% of the minerals have a grain density greater then 2.8 gm/cc.

Grain density values from helium pycnometry on Duvernay samples ranges from 2.436 to 2.614 gm/cc (5 samples), with an average of 2.509 gm/cc, while 2 samples from the Muskwa average at 2.509 gm/cc. Pycnometry results on the Montney range from 2.584 to 2.656 gm/cc, averaging at 2.621 gm/cc for 6 samples. The number of helium pycnometry samples we have analyzed to-date is relatively low and we are working to increase this number using our own work and prior data.

The pycnometry values appear to us to be relatively low given the high weight-percent of relatively heavy minerals in the Duvernay, Muskwa and Montney samples. Grain densities were calculated from the weight-percent data resulting in an average grain density of 2.810 gm/cc in the Duvernay, 2.808 gm/cc in the Muskwa and 2.809 gm/cc in the Montney. We realize the derivation of mineral weight-percent from XRD data may not precisely reflect the mineral content of the sample, hence the grain densities we have calculated are not necessarily precise. The calculated grain densities in all formations are consistently higher than helium pycnometry values by ~0.3 g/cc. The calculated grain density data was then converted from weight-percent to percent volume and the grain densities are still ~0.25 g/cc higher than the pycnometry derived results. The resulting difference in density log total porosity using the calculated grains density versus the pycnometry results is significant.

We are aware that there are elements of error in calculations based on XRD results and there is much to learn about shale sedimentology and effective porosity. If our calculated grain densities are reasonably correct, for example, what then do the pycnometry results represent? One answer is that there is little effective porosity in our shale samples (no larger than a cube), such that even helium molecules cannot penetrate the entire sample. Thus helium grain density estimates will be underestimated.

Conclusions

The main point that we want to make is that the shale formations we have examined in Alberta generally have a very high content of heavy minerals and this results in calculated grain densities that are higher than derived from helium pycnometry by about 0.25-0.3 gm/cc. The application of the higher grain density values results in a significantly higher density log total porosity. We realize that the mineral weight-percent values calculated from XRD patterns are not exact and that this will cause some error in the calculation of differences in grain density relative to helium pycnometry. We are generating additional mineralogical and pycnometry data from these three formations, and others. We hope additional data will help elucidate spatial and temporal variations in shale heavy mineral content and the reasons for differences between helium pycnometry grain density values and calculated grain density values.