Summary

This presentation will discuss how the local geology in the Kaybob region of central Alberta impacts the generation and migration of petroleum in Devonian strata, and how produced fluid sample geochemistry can be used to understand fluid migration and seal containment. The close vertical proximity of conventional and unconventional Devonian-aged reservoirs in the Kaybob region makes this an interesting study area for seal and geochemical stratification based on the compositional and physical properties of produced fluids (e.g. CGR, WGR, CO₂) and core extracts. Geologic formation isochore thickness maps, interpreted subtle overprint structures, and pressure data will be used to explore the evolution of petroleum systems in the Kaybob area.

The primary Devonian source rock in the Kaybob region is the Duvernay Formation (Upper Devonian Woodbend Group) with thickness ranging from 45 to 54 m and present day total organic carbon (TOC) contents ranging from 1 to 6 wt% (Figure 1). Some intervals with TOC ranging from 0 to 1 wt% occurs in the underlying Majeau Lake Fm. In the Kaybob area, the Duvernay Formation is a Type II organic rich, highly siliciclastic mudstone, variably interbedded with silty and carbonate rich intervals. The prolific Duvernay source rock with an aerial extent of 130,000 km² (Preston et al., 2016) has generated an enormous volume of oil and gas that has migrated large distances into numerous reservoirs including the Leduc Formation carbonate buildups of the Rimby-Meadowbrook trend, Simonette, Windfall, and other Devonian aged reservoirs (e.g. Switzer et al., 1994; Allan and Creaney, 1991, Fowler et al., 2001). The 2016 Alberta Energy Regulator best estimate of the total remaining unrisked contingent resources in the Duvernay is 1676 MMboe (354 MMboe proved reserves) which equates to about 350 to 540 trillion cubic feet of natural gas, 7 to 16 billion bbl of natural gas liquids, and 44 to 81 billion bbl of oil (Preston et al., 2016).

One of the interesting aspects of the Kaybob area is that the Duvernay sweet source rock is surrounded by sour Devonian gas and oil reservoirs with high H₂S concentrations ranging from 1 to 30 mol%, such as the prolific ‘North’ and ‘South’ Kaybob Swan Hills Formation oil and gas reservoirs respectively (Krouse et al, 1988). The Duvernay mudstone has generated sweet petroleum fluids with < 0.2 wt% Sulfur consistent with a clastic Type II kerogen with abundant free iron. Figure 1 shows a north to south cross section based on gamma, resistivity and sonic logs of the Duvernay and Majeau Lake mudstones underlain by the Beaverhill Lake Group (BHL) that includes the upper Waterways Member argillaceous carbonate mudstones and the Swan Hills Member carbonate platform and reef buildups. The Duvernay Formation is overlain by the Ireton Fm. calcareous mudstones shale seal, with a thickness ranging from 160 to 330 m in the Kaybob area, that was deposited as regional scale prograding clinoforms (Stoakes, 1980). The Ireton is overlain by Nisku and Wabamun carbonates that also often contain sour H₂S gas and HS⁻ water ranging from 1 to 30 mol% H₂S concentration (IHS,
2017). Figure 1 illustrates how the upper Ireton and lower Waterways seal thicknesses surrounding the Duvernay source rock change through the region and how in some areas the Duvernay may have an easier connection to sour gas fluids in the Swan Hills, Nisku and Wabamun reservoirs. For example, Figure 2 from Chalmers (2016) showed that some Duvernay horizontal wells are seeing breakthrough with up to 0.7 mol% H₂S concentrations reported (IHS, 2017). This was interpreted as a downward hydraulic fracture connection to sour fluids in the Beaverhill Lake Group, and in some areas laterally from the Leduc Formation. Based on Chalmers (2016) analysis, an adequate lower seal thickness of Waterways shale, necessary to reduce H₂S concentrations to 0 ppm in Duvernay horizontal wells, appears to be 40 to 60 m.

Using this geologic context, this presentation will discuss how sour oil and gas reservoirs have migrated in close proximity to the sweet Duvernay liquid rich source rock, how potential petroleum fluids have mixed, and how subtle structural features have influenced petroleum migration and trapping. For example, the Ireton isochore thickness map in Figure 3 shows several interpreted lineaments (red dashed lines labeled Ireton Isochore) that are aligned with the older Swan Hills platform and reef buildups (black dashed lines). The NW-SE lineaments are also aligned with the much younger Jurassic to Cretaceous Fox Creek escarpment that extends over nearly half of Alberta, which suggests that long lived parallel, subtle structural lineaments where active during reservoir deposition such as the Swan Hills platform and reef buildups, as well as during the initial phases of petroleum generation and migration in the Western Canada foreland basin. The presentation will discuss how isochore thickness changes appear to result from subtle movements of basement flexures and depressions that have had a strong impact on reservoir preservation. Fault associated hydrothermal fluids also have contributed to dolomitization enhanced porosity in the Swan Hills locally shown by many Alberta studies. For example Eccles and Berhane (2011) discuss anomalously high lithium concentrations in the Devonian strata of the Kaybob region, which has likely resulted from hydrothermal and/or Devonian evaporate processes.

Figure 1 – Geologic cross section Ireton, Duvernay and Beaverhill Lake (Waterways & Swan Hills) formations, plus a Duvernay isochore thickness map inset showing surrounding Leduc reefs (Figure from Chalmers, 2016).
Figure 2 – Risk map for Duvernay horizontal wells to encounter sour \( \text{H}_2\text{S} \) gas in produced fluids based on Waterways member mudstone plus Majeau Lake mudstone and Duvernay lower carbonate thickness (Figure modified from Chalmers, 2016).

Figure 3 – Ireton isochore thickness map based on formation top picks from 406 well petrophysical logs, interpreted Ireton isochore lineaments plus IHS ‘Sherwin Geoedges’ (2017) for Leduc and Swan Hills reef and platform edges.
Acknowledgements

References


