Relating the Composition of Rock Volatiles to Thermal Maturity Parameters – Insights into Maturation and the Role of Structure on the Bakken Petroleum System

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Abstract

The U.S. Geological Survey analyzed samples from seven cores containing Devonian–Mississippian Bakken Formation source rocks across Williston Basin in North Dakota and Montana. The upper and lower source rock intervals were sampled to determine compositional properties and thermal maturity. Routine bulk organic geochemical, mineralogical, and petrographic analyses were conducted along with rock volatiles stratigraphy (RVS) analysis. The RVS analysis utilizes light hydrocarbons (HC, C_1-C_{10}) and approximately 20 other non-HC gases that are not typically measured by standard techniques, to evaluate the effects of faults and how they influence petroleum migration within the Bakken Formation. Routine analyses provided information on source rock quality, mineralogy, and thermal maturity. RVS volatile compounds entrained in rock samples by crushing the material and applying a gentle vacuum extraction, followed by condensing the volatiles on a liquid nitrogen cryo-trap. Warming of the trap separates the volatiles that are then analyzed by a mass spectrometer. Volatiles that do not condense are analyzed from the cryo-trap headspace gas. In addition to light HCs, water, CO_2, noble gases, and several sulfur compounds are evaluated. Two sequential vacuum extractions (20 and 2 mbar) performed on the same sample provide insights into rock properties. Correlations between several source rock parameters and those derived from the RVS data were observed, including an increase in HC liquids content with increasing thermal maturity through the oil window and increasing gas-to-oil ratios and gas dryness at higher maturities along with trends between C_4 and C_5 isomer ratios. Sulfur species, water, and other analytes from RVS show similar stratigraphic trends, some that are specific to the upper or lower Bakken intervals. Several of the deepest cores are proximal to known faults and show a severe depletion in light HC content and substantial molecular fractionation of some compounds. Comparison of these samples to others of similar maturity from non-faulted areas indicate the depletion and fractionation are related to fault proximity. RVS data provide a unique window into the evolution of light HCs during increasing maturation relative to commonly used bulk organic geochemical methods. For example, the S1 peak (~300°C) from programmed temperature pyrolysis does not capture the $<C_8$ HC range and even shale-specific pyrolysis methods do not separate the individual species of light HCs. In addition to what can be gleaned from the light HCs, additional information is generated for individual C_8-C_{10} HCs and numerous non-HC species measured by RVS. The effects of faults on volatiles entrained within some samples are not readily apparent from other bulk measurements. When tied to field performance and history, RVS datasets can offer valuable insights into understanding the maturation and migration history of a petroleum system.